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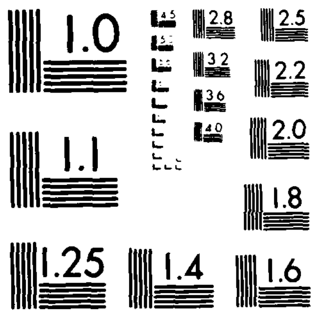

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The High Altitude Pollution Program (1976—1982)

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N. Sundararaman

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16. Abstract

The High Altitude Pollution Program (HAPP) was initiated by the Federal Aviation Administration in 1976 in order to assess the effects of aircraft engine emissions on the upper atmosphere. Its predecessor, the Climatic Impact Assessment Program (1971-1975) conducted by the U.S. Department of Transportation, focused international attention on the ozone depletion problem.

This final report documents the conclusions of the studies funded by HAPP from 1976 until the program was terminated in 1982. Scientific considerations of the impacts of aircraft engine emissions on the stratosphere and troposphere are discussed. Major HAPP accompl:shments in the areas of engine emissions, laboratory studies, field measurements, and modeling are summarized. Current evaluations of the effects of aircraft engine NO_x emissions (through 1984) are also contained in the report.

Based upon the studies undertaken, it appears that there is no immediacy of concern with regard to ozone and climatic changes that may result from the operations of civilian aircraft at this time.

Three appendices provide supplemental information. Appendix A lists the contracts referred to under "Major HAPP Accomplishments." Appendix B is a bibliography of reports, published journal articles, and oral presentations supported by HAPP funds. The HAPP Scientific Advisory Committee is identified in Appendix C.

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THE HIGH ALTITUDE POLLUTION PROGRAM (1976-1982)

I. INTRODUCTION

The High Altitude Pollution Program (HAPP) was initiated by the Federal Aviation Administration (FAA) in 1976. The FAA took this action following the conclusions of a study on potential threats to the earth's environment from the exhaust emissions of civilian supersonic transports (SST's). The study, known as the Climatic Impact Assessment Program (CIAP), had been conducted by the U.S. Department of Transportation (DOT) in recognition of a perceived threat likely to be posed by the-then anticipated fleets of SST's and had been concluded in 1975 (1). Concurrently with its own study, the DOT had requested the National Research Council of the U.S. National Academies of Sciences and Engineering (NAS/NAE) to undertake an independent assessment of the problem (2).

Principal Concerns:

The principal aircraft-related environmental concerns for flights in the upper atmosphere, especially in the stratosphere, were two:

(1) The amount of ozone in the stratosphere might be reduced, so that its effectiveness in shielding life on the earth's surface from biologically-harmful ultraviolet (BUV) solar radiation would be lessened. This lessening would have a predictable effect, namely, of an increase in the incidence in skin cancer (3); other biota may also be affected by the enhanced BUV. The original concept was that the water vapor in the engine exhaust would deplete ozone through chemical reactions in the stratosphere. By the time CIAP was concluded, it had been firmly established that the nitrogen oxides (abbreviated usually as NO_x and referring to nitric oxide, NO, and nitrogen dioxide, NO_2, together) in the exhaust could catalytically destroy ozone; water vapor did not contribute to the ozone loss. There was, however, disagreement as to the magnitude of the ozone depletion and much uncertainty in its calculations (see below).

(2) The heat balance of the earth, and thereby its climate, might be altered, leading to alteration of regional temperature, wind and precipitation patterns. This could be caused by one or both of the following mechanisms: (1) aerosol particles formed in the stratosphere from sulfur dioxide emissions in the engine exhaust could reduce the sunlight reaching the ground and (2) decreases in stratospheric ozone would increase both the incoming solar radiation (in the ultraviolet) and the outgoing earth's radiation (in the infrared). Again, the calculation of the net effect was subject to much uncertainty.

It may be noted here that the emissions of nitrogen oxides result from the operation of the jet engine at high combustor temperatures; the higher the temperature, the more would be the NO_x emissions. The nature and composition of the actual aviation kerosene used has no effect on these emissions because, when air passes through the combustor at high temperature, it is the nitrogen and the oxygen in the air that chemically form NO_x. On the other hand, the composition of the fuel is critical for sulfur dioxide (and water vapor) emissions; the sulfur in the fuel is transformed into sulfur oxides during combustion.

Conclusions of Pre-HAPP Studies:

While differing on specifics, both the CIAP and the NAS/NAE studies agreed that very large (emphasis added) fleets of SST's would lead to significant ozone decreases. The NAS/NAE study calculated a more severe effect than the CIAP study. Concurrent studies (4,5) on the question mounted by the Governments of Great Britain and France (the two nations engaged in developing the Concorde at the time) agreed as to the potential for NO_x to destroy ozone catalytically, but calculated far less severe effects than the CIAP study. For example, a reduction of 0.25 percent in the global ozone content was calculated to result from 80 Concorde-like aircraft by NAS/NAE, from 120 of such aircraft by CIAP and from 430 and 325 such aircraft by the respective studies in U.K. and France. The overall uncertainty in all of these calculations ranged from a factor of 0.1 to 10 (1,2).

Only the CIAP study attempted to make quantitative estimates of likely temperature changes at the earth's surface due to fleets of SST's. The calculated effect was quite small a decrease, for example, of less than one-hundredth of one degree Fahrenheit, for continued operations of a fleet of 100 Concorde-like aircraft (1).

From these studies, it was reasonable to assume that the amount of ozone depletion could be controlled by controlling NO_x emissions from the engines, and similarly to control climatic consequences by controlling the sulfur dioxide emissions. Other pollution-avoidance measures were also possible, such as limiting the amount of stratospheric flight to put a "ceiling" on the annual deposition of emissions into the stratosphere or lowering flight altitudes so that emissions at higher altitudes, where the effects were greater according to computer calculations, were minimized or altogether avoided.

The CIAP study had suggested in its conclusions, as one course of action: "Develop, within the next year, a plan for a proper program for international regulation of aircraft emissions and fuel characteristics for whatever stratospheric flight operations may evolve in the future" (1). Given this recommendation and the uncertainties in the ozone depletion calculations, it became necessary for the FAA to undertake its High Altitude Pollution Program (HAPP), a sequel to CIAP, in order to "quantitatively determine the requirements for reduced cruise-altitude exhaust emissions, and, in conjunction with the Environmental Protection Agency (EPA) and the International Civil Aviation Organization (ICAO), to ensure that, if necessary, appropriate regulatory action is taken to avoid environmental degradation" (6). By law, ultimate responsibility for setting standards for engine exhaust emissions rests with the EPA; FAA has responsibility for setting standards in regard to specifications of jet fuel. Development and enforcement of regulations in both areas are the responsibilities of FAA.

Other Sources of Stratospheric Pollution:

As HAPP was getting under way, it had become clear that human activities other than stratospheric flights posed potentially greater threats to the ozone layer. The most concern centered on chlorofluoromethanes, a class of chemicals which include the inert compounds used in aerosol spray cans (see, for example, 7,8). Other potential sources of concern were nitrogenous fertilizers and nuclear detonations. As such, it became evident that the FAA did not have primary responsiblity within the U.S. Executive Branch for environmental protection with regard to pollution of the stratosphere. Responsibility for major portions of this work resided within other agencies, as directed by various Acts of Congress, indicated below:

Stratospheric ozone protection.........................EPA
Comprehensive program of research, technology,
  and monitoring of upper atmospheric phenomena.........NASA
Research and development of advanced gas turbine
  systems for aeronautical applications.................NASA
Environmental monitoring...............................NOAA
Energy research and development........................DOE
Basic research...NSF

In addition, the U.S. National Academies of Sciences and Engineering had always performed critical reviews and summarized state-of-the-art conclusions of the problem of stratospheric pollution.

HAPP was a program stressing upper atmospheric impacts of aviation pollution.

International Coordination:

It was also recognized that upper atmospheric pollution, being a global problem, cannot be controlled by the unilateral action of one nation alone. It requires cooperation and establishment of common goals by all nations. Thus, HAPP was to be closely coordinated with international activities such as those of ICAO, WMO*, UNEP*, WHO* and other appropriate U.N. bodies, as well as individual foreign governments. In particular, at the time of the Secretary of Transportation's Decision on Concorde Supersonic Transport (9), he directed the FAA to lead efforts to develop and implement a Tripartite Agreement on Monitoring of the Stratosphere (10) among France, the United Kingdom of Great Britain and Northern Ireland, and the United States of America.

* WMO - World Meteorological Organization
UNEP - United Nations Environment Program
WHO - World Health Organization

HAPP Structure:

The program was organized under seven work elements (see Fig. 1). In order to assess the effects of aviation on the upper atmosphere, a data base was initiated and maintained on engine emissions which included not only projected future scenarios, but also actual past emissions. This engine emissions data base formed the input for calculations by stratospheric models of both anticipated effects and past trends. The models were one- and two-dimensional computer simulations of the known physics and chemistry of the stratosphere. Their outputs yielded quantitative changes of ozone and climate resulting from aircraft emissions. Associated with this work element was an effort to identify and reduce, if possible, the uncertainties in the model calculations. The modeling element formed the central piece of the entire program, for the models are the only available means to calculate the likely consequences of future actions. Laboratory measurements were required to update and maintain an accurate data base on important chemical reactions. Accurate field measurements of the atmospheric concentrations of key trace gases were needed, both to check the models' reliability and to provide input data to improve the models. The program elements were necessarily interactive and their interrelationships are indicated in figure 1 by connecting arrows. None of these elements, except the one on emissions data base, was implemented in isolation by the FAA; as stated earlier, other agencies undertook similar programs and the FAA coordinated its program with those of others both formally and informally in order to achieve maximum cost effectiveness.

While the models can calculate the expected physical result (e.g., ozone decrease) for given emission scenarios, the assessment of the significance of that result is a different matter. It is clearly not the responsibility of the FAA to make implicit or explicit judgments regarding the "permissibility" of a given amount of environmental pollution. That responsibility has been delegated to other agencies, or falls within the purview of Congress. Thus, FAA's assessment of the significance of a model calculation has to be made in the light of the activities and ongoing programs of other agencies and institutions: an assessment can have meaning only if there is an accepted standard with which the model result can be compared; in the absence of such a standard (which at this writing does not exist for stratospheric air quality), an assessment should take into account available, verified knowledge of potential harm to public safety and welfare (such as adverse health effects). The result of an assessment activity is a set of regulatory policy options for consideration by the agency. As for the remaining element, monitoring, the responsibility rests with the National Oceanic and Atmospheric Administration (NOAA); the objective of this element in HAPP was to ensure that the aviation-related concerns were brought to the attention of NOAA and relevant international agencies. Both assessment and monitoring elements encompass a large measure of coordination with national and international agencies.

Program Elements

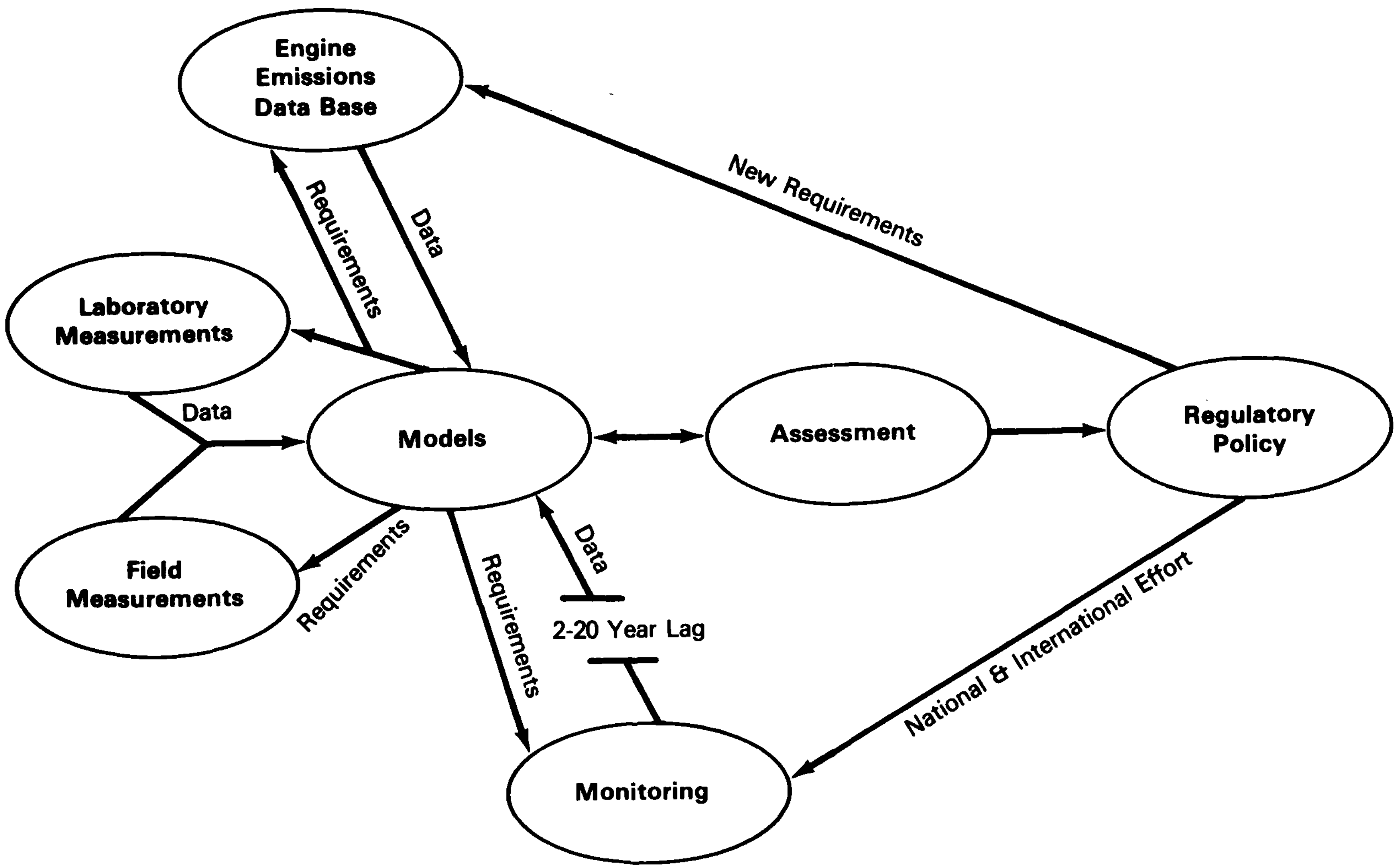

Figure 1

HAPP Scientific Advisory Committee:

In order to review the scope, adequacy and priorities of HAPP, advise on its areas of research, and appraise its analyses, in 1978 the FAA enlisted the counsel of a technical advisory group known as the High Altitude Pollution Program Scientific Advisory Committee (HAPPSAC). Because of the interdisciplinary nature of HAPP work, the Committee consisted of internationally-recognized experts from the areas of aircraft engine emissions measurement, aircraft operations, stratospheric measurements, computer modeling of stratospheric processes, laboratory measurements related to stratospheric phenomena, and stratospheric monitoring. The Committee was chaired by Professor F.S. Rowland of the University of California at Irvine, California, and met five times between 1978 and 1982 (11). See Appendix C.

II. SCIENTIFIC CONSIDERATIONS OF THE PROBLEM OF THE IMPACTS OF AIRCRAFT ENGINE EMISSIONS ON THE UPPER ATMOSPHERE

Cruising altitudes for civilian aircraft in the foreseeable future can be expected to be confined to about 60,000 feet (18 km, roughly) or below. Thus, the region of concern for cruise altitude emissions would be from about the so-called mixing layer (about 1 to 3 km above the ground, where air pollution problems arise due to ground level emissions from, for example, automobiles and power plants) to about 25 km above the ground. This region contains the tropopause at about the 10 km altitude below which almost all known weather phenomena occur; it also contains the atmospheric region where most of the ozone is found (the maximum density of ozone occurs near 25 km in our latitudes). Unfortunately, this is also the region where atmospheric dynamics is complex and atmospheric chemistry not completely understood, despite significant research efforts by various Federal agencies. Relevant properties of this region for application to the aircraft problem are described below.

Absorption of Sun's Radiation and Resulting Temperature Stucture:

Slightly less than one half of the solar radiation falling on top of the atmosphere reaches the ground. The rest is partly reflected by the clouds and the atmosphere and partly absorbed by them. The heated ground, in turn, heats the part of the atmosphere below the tropopause (the troposphere); hence, the temperature in the troposphere generally decreases steadily from the ground up reaching a minimum at the tropopause. About 3 percent of the incoming solar radiation, in the ultraviolet part of the solar spectrum, is directly absorbed by ozone in the stratosphere (the region above the tropopause extending up to about 50 km); this absorption is responsible for the temperature structure of the stratosphere, where the temperature generally increases with height. Some of the energy in the solar ultraviolet wavelengths is also responsible for the photochemistry occurring in this part of the atmosphere; in general, the shorter the (ultraviolet) wavelength, the less it penetrates into the atmosphere.

One consequence of the different temperature structures of the troposphere and the stratosphere is up-and-down convective motion in the troposphere leading to cloud formation and rain, and hence to quick removal of injected aircraft effluents; such motion is inhibited in the stratosphere leading to long residence times for engine emissions. The residence time of an emittant is important in that longer times raise the probability of the emittant participating in chemical reactions.

Atmospheric Motion and Transport of Emissions:

Except in regions of high convective activity (e.g., cumulonimbus or thunderclouds in the troposphere) motion in the atmosphere is largely horizontal. Vertical motion is not completely absent, however; on the average, horizontal wind speeds exceed vertical speeds by ratios of 500-1000 to 1. The air flow resembles an undulating, meandering river with eddies circling the globe. The meanderings can carry air north-south or south-north while the larger eddies, by churning the atmosphere, can achieve good mixing of, for example, cold polar air and warm tropical air. Generally, the motion is zonal, i.e., east-west or west-east. The small vertical velocities (of the order of millimeters or centimeters per second) transport engine emissions from the troposphere to the stratosphere and vice versa, while the horizontal velocities (measured in knots and including the jet stream) carry them around the globe unless they are removed by processes involving chemical transformations or rainout/washout. The vertical motions are, of course, greatly inhibited in the stratosphere.

In the troposphere, the average circulation is westerly in the middle latitudes and easterly in the tropics at least above the mixing layer (there are, of course departures from this picture such as the monsoon winds). Winds generally increase in speed reaching jet stream velocities near the tropopause. In the stratosphere, the circulation is easterly in summer and westerly in winter (again, this average pattern may break down a few times during winter phenomena known as sudden warming events found in the Northern Hemispheric high latitudes).

To understand the impacts of aircraft emissions on the upper atmosphere (i.e., upper troposphere and lower stratosphere, 3 - 25 km), it is necessary to understand how tropospheric and stratospheric air are exchanged, for emissions at one altitude will necessarily reach other altitudes; and the residence time of the emissions increases from the troposphere to the stratosphere.

It is thought that all upward transport from the troposphere to the stratosphere occurs in a rising air column in the equatorial zone (this rising column is known as the ascending branch of the tropical Hadley cell). Further, this transport is thought to occur mainly through cumulonimbus towers, which often penetrate to stratospheric altitudes in these latitudes (12).

The downward transport of air from the stratosphere to the troposphere is known to occur in the middle and high latitudes through tropopause "folds." These folds are akin to breaks in the tropopause and appear to be associated with jet streams. Whether or not air can go from the troposphere to the stratosphere through these folds remains to be clarified (see, for example, 13).

Stratospheric Ozone Chemistry:

1. Ozone production.

An ozone molecule contains three atoms of oxygen (O_3) while an oxygen molecule has two oxygen atoms (O_2). The only way to form ozone in the atmosphere is to have an oxygen atom (O) chemically combine with an oxygen molecule (O_2) via the reaction:

$$O + O_2 + M \longrightarrow O_3 + M \qquad (1)$$

where M is a third body such as a nitrogen molecule. There are three ways of obtaining O, all of them through photolysis:

(1) by photodissociation of an oxygen molecule, O_2, by solar radiation of wavelengths shorter than 242 nm. (nm stands for nanometer which is a billionth of a meter.) This radiation does not penetrate to heights below 25 km.

(2) by photodissociation of a nitrogen dioxide (NO_2) molecule by radiation in the 375 - 420 nm wavelength range. This radiation reaches all the way to the ground.

(3) by photodissociation of an ozone molecule by both visible (450 - 650 nm) and ultraviolet radiation. Of the latter, no radiation below about 295 nm reaches the ground owing to its being absorbed by ozone in the upper atmosphere. The ozone photodissociation process, of course, does not serve to increase ozone, since the oxygen atom produced can either react with another oxygen molecule or with some other molecule such as water vapor (H_2O), nitrous oxide (N_2O) or methane (CH_4).

In the upper atmosphere, oxygen photolysis together with reaction (1) produces ozone. The source region for the globe is the mid-stratosphere in the tropics (2). From here the ozone is transported downward and poleward. Near the ground, in areas such as cities prone to air pollution, ozone is produced by nitrogen dioxide photolysis and reaction (1). This point is important and has implications for aircraft engine emissions (see below).

2. Ozone destruction.

Through the stratosphere-troposphere downward exchange processes, some of the ozone passes into the troposphere, reaches the ground and is destroyed there by surface contact. In addition to this, there are four chemical removal mechanisms that are known to destroy ozone in the atmosphere: they are the so-called odd-oxygen (O_x), odd-hydrogen (HO_x), odd-chlorine (ClO_x) and odd-nitrogen (NO_x) mechanisms.

2a. Odd-oxygen removal mechanism:

An oxygen atom produced in oxygen (molecule) or ozone photolysis can combine with an ozone molecule to produce two oxygen molecules:

$$O + O_3 \longrightarrow 2\ O_2 \tag{2}$$

This reaction takes place above the tropopause to altitudes above the stratospause. In the troposphere, the O produced in O_3 photolysis generally combines with water vapor since it is more abundant than ozone in this region. Originally, the balance between ozone production in the upper atmosphere and its destruction by the odd-oxygen cycle together with its loss at the ground was thought sufficient to explain the amount of ozone present in the atmosphere.

The odd-oxygen cycle is a natural cycle, with no intervention by human activities.

2b. Odd-hydrogen removal mechanism:

This really consists of four cycles.

First cycle:
$$\begin{array}{l} O + HO \rightarrow H + O_2 \\ H + O_2 + M \rightarrow HO_2 + M \\ O + HO_2 \rightarrow HO + O_2 \\ \hline \end{array}$$

Net: $O + O \rightarrow O_2$

Second cycle:
$$\begin{array}{l} O + HO \rightarrow H + O_2 \\ H + O_3 \rightarrow HO + O_2 \\ \hline \end{array}$$

Net: $O + O_3 \rightarrow 2\ O_2$

Third cycle:
$$\begin{array}{l} HO + O_3 \rightarrow HO_2 + O_2 \\ HO_2 + O \rightarrow HO + O_2 \\ \hline \end{array}$$

Net: $O + O_3 \rightarrow 2\ O_2$

Fourth cycle:
$$\begin{array}{l} HO + O_3 \rightarrow HO_2 + O_2 \\ HO_2 + O_3 \rightarrow HO + 2\ O_2 \\ \hline \end{array}$$

Net: $2\ O_3 \rightarrow 3\ O_2$

In these four cycles it may be noted that odd-hydrogen radicals (H, OH, HO_2) are generated at the completion of a cycle while ozone and atomic oxygen are lost. It is this catalytic nature of the reactions that render HO_x and other trace species (see below) important in disproportion to their abundance.

The first and second cycles are important above 40 km, the third cycle between 40 and 30 km and the fourth cycle below 30 km. The source of HOx radicals is the reactive combination of H_2O with an excited oxygen atom (the singlet atom, viz., $O(^1D)$):

$$H_2O + O(^1D) \rightarrow 2\ HO$$

The odd-hydrogen cycle is also a natural cycle, with no known contribution from human activities.

2c. Odd-chlorine removal mechanism:

There are three cycles in the odd-chlorine catalysis of O_3:

First cycle:

$$Cl + O_3 \rightarrow ClO + O_2$$
$$ClO + O \rightarrow Cl + O_2$$

Net: $O + O_3 \rightarrow 2\ O_2$

Second cycle:

$$Cl + O_3 \rightarrow ClO + O_2$$
$$ClO + HO_2 \rightarrow HOCl + O_2$$
$$HO + O_3 \rightarrow HO_2 + O_2$$
$$HOCl + E \rightarrow HO + Cl$$ (E stands for radiative energy)

Net: $2\ O_3 \rightarrow 3\ O_2$

Third cycle:

$$Cl + O_3 \rightarrow ClO + O_2$$
$$ClO + NO_2 \rightarrow ClONO_2$$
$$NO + O_3 \rightarrow NO_2 + O_2$$
$$ClONO_2 + E \rightarrow Cl + NO_3$$
$$NO_3 + E \rightarrow NO + O_2$$

Net: $2\ O_3 \rightarrow 3\ O_2$

Cl and ClO are regenerated at the end of the cycle while O_3 is lost. The first cycle dominates above about 25 km with some contribution from the second cycle. Between 15 and 25 km, all three cycles are approximately equally important.

There are both natural and anthropogenic sources of chlorine:

natural............methyl chloride, some chloroform (see, for example, 14)

anthropogenic......predominantly chlorofluorocarbons used primarily in aerosol spray cans as propellants, in refrigeration and automobile air conditioning; other halocarbons such as methyl chloroform and carbon tetrachloride.

The major threat to the ozone layer is now thought to come from chlorofluorocarbons.

2d. Odd-nitrogen removal mechanism:

There are two cycles:

First cycle:

$$NO + O_3 \rightarrow NO_2 + O_2$$
$$NO_2 + O \rightarrow NO + O_2$$

Net: $$O + O_3 \rightarrow 2\ O_2$$

In this cycle, the NO_2 formed may be photolyzed to yield O; in this case, O will react with O_2 in a three body process to form O_3. If this happens, both NO and O_3 are reformed and the cycle becomes a do-nothing cycle. Or the NO_2, or part of it, may react with O yielding NO and O_2. Hence, removal of O_3 depends critically upon the availability of both NO_2 and O. Oxygen atoms have been observed throughout the stratosphere above 28 km (8); it is possible to calculate their abundance below that altitude and it increases with height.

Second cycle:

$$NO + O_3 \rightarrow NO_2 + O_2$$
$$NO_2 + O_3 \rightarrow NO_3 + O_2$$
$$NO_3 + E \rightarrow NO + O_2$$

Net: $$2\ O_3 \rightarrow 3\ O_2$$

The first cycle is by far the predominant cycle, extending from 15 to at least 50 km.

There are both natural and anthropogenic sources for odd-nitrogen species.

3. Sources of odd-nitrogen:

The natural sources are production by lightning, forest fires, cosmic ray/auroral particles' interaction with the very high atmosphere (above about 45 km), downward transport of the oxidation products of biogenic nitrous oxide (N_2O) and exhalation from soils. The anthropogenic sources are aircraft engine emissions, nitrous oxide generated from chemical fertilizers, combustion of fossil fuel (including in automobiles and power plants), biomass burning, oxidation of ammonia from fertilizer volatilization and, potentially, nuclear detonations.

Of these, sources near the ground or in the lower troposphere such as lightning, forest fires, exhalation from soil, combustion of fossil fuel, biomass burning and ammonia oxidation occur in regions of rainout/washout; also much uncertainty exists as to their strength, except for surface fossil fuel combustion (15). NO_x produced in the very high atmosphere (i.e., above 50 km) such as that due to cosmic rays/auroral particles is unlikely to affect the background concentrations in the upper troposphere and the lower stratosphere.

Thus, in the region of interest for aircraft operations, the sources are aircraft engine emissions and oxidation of N_2O (from both natural biogenic activity and nitrification/denitrification transformation of chemical fertilizers). In the oxidation of N_2O, NO is formed in the reaction $N_2O + O(^1D) \rightarrow 2\ NO$. N_2O is inert in the troposphere (i.e., it does not participate in chemical reactions nor is it easily rained/washed out) and hence is transported to the lower stratosphere where it can react with oxygen atoms. The NO (and perhaps the subsequent NO_2 produced by $NO + O_3 \rightarrow NO_2 + O_2$) can be transported to the troposphere through tropopause breaks.

Table 1 lists the relative strengths of atmospheric sources of odd-nitrogen. In this table, the unit of injection rate or source strength is Tg N = 10^{12} grams (as nitrogen atom). In some cases, values are given for 1975 as well as projections for 1990. From the table, it is evident that the aircraft source can be comparable to, or even slightly more than, the other important source, viz., transport of oxidation products of nitrous oxide; the latter, however, does not include potential increases due to greater use of chemical fertilizers.

The relative contributions of the various catalytic ozone removal mechanisms as a function of altitude in the stratosphere is given in Table 2. All values are normalized to the local rate of ozone production by oxygen photolysis.

Tropospheric Ozone Chemistry:

Only about 10 percent of the total amount of ozone found in the atmosphere resides in the troposphere. The origin of tropospheric ozone is still a subject of controversy. Until the mid 70's, the accepted classical view was that ozone was transported from the stratosphere downward into the troposphere by some mechanism such as tropopause break and that there was no local production above the missing layer (there is, of course, ozone production near the ground in polluted urban atmospheres). Current research indicates that gas phase photochemical production and destruction of ozone in the upper troposphere may be at least as important as injection of ozone from the stratosphere.

Ozone can be produced in the troposphere by the oxidation of CO (carbon monoxide):

$$\begin{array}{ll}
 & CO + OH \rightarrow H + CO_2 \\
 & H + O_2 + M \rightarrow HO_2 + M \\
 & HO_2 + NO \rightarrow HO + NO_2 \\
 & NO_2 + E \rightarrow NO + O \\
 & O + O_2 + M \rightarrow O_3 + M \\
\hline
\text{Net:} & CO + 2\ O_2 + E \rightarrow CO_2 + O_3
\end{array}$$

TABLE I

ATMOSPHERIC SOURCES OF ODD-NITROGEN

SOURCE	INJECTION RATE (Tg N/YR)	MEAN INJECTION HEIGHT(KM)	LAT. RANGE OF INJECTION
Aircraft	0.15(1975) 0.53(1990)	6-16	Northern Hemisphere
Fossil Fuel	19.0(1975) 27.0(1990)	Ground Level	Mid/High Lat. Northern Hemisphere Mid Lat.
Biomass Burning			
- Forest Fires - Other	1.7 3.3(1975) 3.8(1990)	1-2 Ground Level	Tropics
Lightning	5.7	7-12 and lower	Tropics Land Only
Transport from Stratosphere	0.5*	Tropopause	Mid Lat.?
Cosmic Rays	0.06	Upper Troposphere	
Exhalation From Soils	c.10.0	Ground Level	
Ammonia Decomposition	<8.0	Throughout Troposphere	

*Total odd-nitrogen of which 5 - 20% is NO_x.

TABLE 2 *

RELATIVE CONTRIBUTIONS FOR VARIOUS CATALYTIC
OZONE DESTRUCTION PROCESSES
(24 HOUR AVERAGE)

ALTITUDE (KM)	ODD-OXYGEN MECHANISM %	ODD-CHLORINE MECHANISM %	ODD-HYDROGEN MECHANISM %	ODD-NITROGEN MECHANISM %
50	25	4	52	7
45	29	10	31	24
40	18	16	10	53
35	11	13	5	68
30	10	8	5	69
25	12	5	9	78
20	11	1	27	70

HO_x and NO_x act as catalysts in producing ozone from CO and O_2. The efficiency of this cycle depends on the relative concentrations of these catalytic species.

HO_2 can also react with O_3; even though this reaction is slower than its reaction with NO, for low concentrations of NO, the preferred path is for HO_2 to react with O_3. Such a preference will lead to the following consequence:

$$
\begin{array}{ll}
 & CO + HO \rightarrow H + CO_2 \\
 & H + O_2 + M \rightarrow HO_2 + M \\
 & HO_2 + O_3 \rightarrow HO + 2\ O_2 \\
\hline
\text{Net:} & O_3 + CO \rightarrow CO_2 + O_2
\end{array}
$$

For low concentrations of NO, then, ozone is catalytically destroyed by HO_x. When NO concentrations are above about 10 parts per trillion (ppt), i.e., when more than 10 molecules of NO are present in a trillion molecules of air, ozone production dominates.

* For a full discussion of the details, see 8.

There is another process by which ozone may be formed. Methane (CH_4) may combine with HO in an oxidation chain involving NO:

$$CH_4 + HO \rightarrow CH_3 + H_2O$$
$$CH_3 + O_2 + M \rightarrow CH_3OO + M$$
$$CH_3OO + NO \rightarrow CH_3O + NO_2$$

This is followed by NO_2 photolysis and ozone formation (16).

Both CH_4 and CO are present in the natural troposphere in parts per million and fractional parts per million ranges, respectively. About 80 percent of the methane is of biological/microbiological origin from such places as swamps and paddy fields; the rest comes from natural gas wells. Roughly half the CO is of anthropogenic origin mainly from automobiles and space heating. Also there is four times as much CO in the Northern Hemisphere as there is in the Southern, attesting to the importance of anthropogenic sources. Some of the CO may pass into the stratosphere from the troposphere, for example, through the ascending branch of the Hadley cell.

Because of the faster rate for the reaction of CO with OH, CO oxidation is the dominant mechanism for O_3 production in the troposphere.

Climatic Consequences:

CIAP had concluded that the primary threat to climate, if any, would come from sulfur dioxide (SO_2) in the engine exhaust as far as aircraft emissions are concerned. Calculations made with CIAP models showed very small effects (see Conclusions of Pre-HAPP Studies above). There was realization, of course, at the end of CIAP, that local changes in ozone concentrations due to catalytic destructive processes by NO_x could lead to subtle climatic effects (17). This question has been further examined in the last few years and a brief summary of the state-of-the-art understanding follows.

Just as any other body in the universe, the earth also radiates electromagnetic energy, the wavelength range of its emissions depending upon its average temperature. It turns out, then, that much of the terrestrial emission takes place in the 5,000 - 20,000 nm range. The only gases absorbing this energy in the natural atmosphere are trace gases such as water vapor, carbon dioxide and ozone; the bulk of the atmosphere (nitrogen, oxygen, etc.) is transparent to this radiation. Some examples of anthropogenic gases that can contribute to its absorption are chlorofluorocarbons, nitrous oxide and about 25 other man-made compounds, in addition to carbon dioxide.

The earth's energy absorbed by the trace gases is in turn partly reradiated downward to the lower atmosphere and the ground; this reradiation is the so-called "greenhouse" effect.

Ozone has strong absorption in the wavelength region at 9,600 nm in addition to its absorption of direct solar energy in the ultraviolet wavelengths. Thus, changes in ozone density of various amounts at various heights (i.e., an alteration in the ozone altitude profile) will affect the absorption of direct sunlight and also modify the greenhouse effect.

Stratospheric ozone reduction, for example, will increase the transmission of direct solar radiation to the troposphere and ground, thereby heating them both. It will, at the same time, reduce the absorption of terrestrial radiation by ozone (and hence the greenhouse effect) leading to greater loss of this radiation to space. These two processes have opposing effects on surface temperature and any net change in the latter has to be calculated for each given profile change.

Tropospheric ozone increase, on the other hand, will decrease direct solar transmission to the ground and increase the greenhouse effect. Again, the two effects are opposing, the former leading to a surface cooling while the latter increases surface heating. The actual net effect will depend on the details of the profile change.

For assessment purposes, studies of climate (surface temperature) change are carried out with the so-called one-dimensional radiative-convective models. Their most recent calculations show that ozone changes in the lower stratosphere and upper troposphere (the region of interest for aircraft flights) are more effective than changes in other regions of the atmosphere in causing a surface temperature change (see, for example, 18); on a per molecule basis, an ozone change at 10 km is 4 - 5 times more effective than the same change at 20 km altitude (19).

Effects of Temperature Change on Ozone Change:

Climate-chemistry interactions are also important for stratospheric ozone depletions. The chemical rate coefficients of many reactions in ozone chemistry are temperature-dependent. Any cooling of the stratosphere, should it occur, has the effect of reducing ozone depletions brought about by the catalytic removal mechanisms; any such reduction of course affects climatic changes in its turn. Thus, there is "feedback" between atmospheric chemistry and climate.

There appears to be one way to decrease stratospheric temperature. CO_2 in the atmosphere has been observed to increase steadily and this has been attributed to increasing use of fossil fuel. This gas reaches the stratosphere from the troposphere by transport mechanisms where it can increase the absorption, and eventual reradiation, of terrestrial radiation.

III. DESCRIPTION OF THE MODEL USED BY THE FAA FOR ITS ASSESSMENT

The High Altitude Pollution Program has suported both one- and two-dimensional models for calculating ozone changes. However, because of the completeness of chemistry and less costly operations, the one-dimensional model has become the accepted FAA assessment model. The model in use was developed by the Lawrence Livermore National Laboratory (LLNL) at Livermore, California. This model was begun during CIAP and has since been improved steadily under HAPP funding over the past several years. It is the primary model used by the National Academy of Sciences for its biennial assessment of the chlorofluorocarbon-induced ozone decreases as well as a present benchmark against which other model results are tested.

The LLNL model includes the troposphere, the stratosphere and the lower part of the mesosphere; it extends from the ground to about 60 km. All atmospheric variables are averaged over latitudes and longitudes so that only their vertical variations are explicitly treated in the model. That is, meteorological quantities like temperature, concentrations of trace species, etc., are allowed to vary only with height. (In a two-dimensional model, these quantities are allowed to vary with both height and latitude; thus, such a model is a step closer to a realistic atmospheric representation than a one-dimensional model.)

All motion is parameterized by using a quantity called the "eddy diffusion coefficient" in the LLNL model. Motion in the real atmosphere, of course, is three-dimensional and occurs over many different time and space scales. In representing a global mean state, however, horizontal motion has no net contribution in the following sense. Removal of trace species from a given latitude/longitude position merely transports the material to another latitude/longitude position at the same altitude. Thus, if one were to average the transport in the horizontal dimension, net transport is zero. For globally-averaged models, then, only vertical transport remains. Such transport is obtained by assuming that it is proportional to the vertical gradient of the mixing ration of the trace species. (Mixing ratio for a given trace species is the ratio of its mass to the mass of air containing it). The constant of proportionality, referred to as the eddy diffusion coefficient, is in practice, inferred from atmospheric observations of some trace gas such as nitrous oxide or methane.

One-dimensional models contain all the known stratospheric chemistry, but highly approximate the motion fields. Nevertheless, they are the most useful models for assessment purposes. It may or may not be possible to base remedial actions solely on their calculations but they provide the first cut at a determination of the need and the immediacy, if any, of regulatory actions.

In general, three-dimensional models (containing variations in altitude, latitude and longitude) represent motion in the most self-consistent manner; they, however, lack the detailed chemistry needed for assessment purposes. Two-dimensional models, though representing mean motions self-consistently, still approximate eddy transport processes in some fashion; chemical calculations with these models are also limiting, since in some instances there is difficulty in specifying needed boundary conditions in two-dimensions. For these reasons, one-dimensional models are preferred for assessment purposes.

IV. MAJOR HAPP ACCOMPLISHMENTS*

In the engine emissions area, a HAPP model to forecast fuel burn by geographic location and altitude based on aircraft fleet projections, whose output can be used to calculate global emissions loading, has been developed (FAA Contract No. DOT-FA77WA-3066). Emissions forecast for NO_x, H_2O and SO_2 for altitudes above 8 km through the year 1990 have been made (FAA Contract Nos. DOT-FA75WA-3574, DOT-FA76WAI-603, and DOT-FA76WA-3757). A long-standing discrepancy in the NO_x emission index that existed in its measurement by two different techniques, one an optical remote method and the other an in-situ probe sampling method, was resolved (Contract No. DOT-FA77WAI-4081). This resulted in accurate emission indices and the correct technique and analysis algorithm for their measurement. An engine emissions forecast model has been developed and is available for use. Actual emissions, using real available data from the Official Airlines Guide, have been computed for the years 1972 - 1980 (Contract No. DTFA01-82-Y-10505).

In the laboratory measurements area, chemical reaction rate coefficients for about 40 reactions were either newly measured or remeasured; in the latter case, the measurements were either to confirm those made by non-FAA sponsored studies, or to pinpoint reaction paths and reaction products, where such information was critical to FAA's concerns. Of major impact among these were HONO + O_3, $O(^3P)$ + N_2O_5 (Contract Nos. DOT-TSC-1201, DOT-TSC-1203), $O(^1D)$ + N_2O (Contract Nos. DOT-TSC-1200, DOT-TSC-1203), OH + ClO (Contract No. DOT-FA78WA-4262), OH + HO_2 (Contract No. DOT-FA79WAI-112), NO + O_3 (Contract No. DTFA01-80-Y-10559), OH + HO_2NO_2 (Contract No. DOT-FA78WA-4228), CH_3O_2 + NO (Contract No. DOT-FA79WA-4393), CH_3O_2 + NO_2 and OH + HNO_3 (Contract No. DOT-FA78WA-4259), CH_3O + O_2 and CH_3O + O_3 (Contract No. DOT-FA79WA-4362), HO_2 + NO and HO_2 + HO_2 (Contract No. DOT-FA77WA-4054), and OH + H_2O_2 (Contract No. DTFA01-80-C-10084). Rate constant determinations for HO_2 + NO, OH + HNO_3 and OH + HO_2NO_2 turned out to be of critical importance. Photolytic parameters and/or quantum yields were determined for NO_2 (Contract No. DOT-TSC-1204), HO_2NO_2 (Contract No. DOT-FA78WA-4248), O_3 (Contract No. DOT-FA78WA-4263) and HO_2CHO

* See Appendix A for identification of contracts listed in this section.

(Contract No. DOT-FA78WA-4264). A continuing effort, jointly with NASA and NBS* was undertaken to update and maintain chemical kinetics data (Contract Nos. RA-76-13-6400223, DOT-FA79WAI-005, DTFA01-80-Y-10532 and DTFA01-81-Y-10519). The solubility of nitrogen oxides and oxyacids was studied with a view to parameterizing the tropospheric rainout/washout processes for model applications (Contract No. DOT-FA78WAI-659).

In the field measurements area, the following projects were completed. Ambient air samples collected with special instrumentation on board Concorde aircraft were analyzed to determine trace gas concentrations (Contract Nos. WI-78-3745-1 and DOT-FA79WA-4285). Stratospheric water vapor measurements were carried out with an existing instrument to maintain historical continuity of the data (Contract No. DOT-FA77WAI-748); a new and more sensitive instrument based upon an entirely novel optical technique for in-situ measurements was developed and intercompared against other existing methods (Contract Nos. DTFA01-80-Y-10568, DOT-FATQWAI-684); existing water vapor data were compiled and analyzed (Contract No. WI-78-3740-1). Possible techniques for the measurement of H_2O_2 were investigated (Contract No. DOT-FA78WA-4232). Two major efforts were undertaken for the development of instrumentation for the simultaneous measurement of NOx species in the upper atmosphere (Contract Nos. DOT-FA76WAI-648, DOT-FA77WA-3949, DOT-FA77WA-3931, DOT-FA77WAI-722, DOT-FA77WA-4080, AIA/CA-13, AIA/CA-17, DTFA01-80-Y-10565, DTFA01-80-Y-10568 and DTFA01-80-C-10039); both were completed successfully and one of them became the focus of a NATO Committee on Challenges to Modern Society study on stratospheric pollution. Radiances measured in the 9800 nm wavelength region (where ozone has absorption bands) by the USAF Block 5D Series satellites, which would otherwise have been discarded due to the operational nature of the Series, were saved and used for total ozone retrieval, thus filling an approximately one-year gap in the total ozone data between the loss of the Nimbus 4 satellite instrument and the launching of the Nimbus 7 instrument (Contract No. DOT-FATQWAI-653). Ozone data from the existing ground-based observing network were recalibrated and intercompared (Contract No. DOT-FA78WAI-850); the available instruments for rocketborne measurements of the ozone profile (the only routine technique available for the 30 - 60 km altitude range) were intercompared (AIA/CA-12). An effort was also undertaken to develop the concept of a global tracer experiment for transport studies (Contract No. DOT-FA78WAI-860) since transport processes are quite important in the atmospheric region where almost all the aircraft cruise emissions occur.

In the modeling area, the emphasis was on building a one-dimensional model (the LLNL model) incorporating comprehensive stratospheric chemistry, simplified tropospheric chemistry and rainout/washout

* NBS - National Bureau of Standards

processes, and transport parameterization based on all available tracer measurements (Contract Nos. DOT-TSC-(RA)-76-1, DOT-FATQWAI-653 and DOT-FA79WAI-034). Development of two-dimensional models was also supported mainly for the purpose of defining the latitudinal variations of the aircraft injection effects; aircraft emissions are, by and large, confined to the North Atlantic corridor (Contract Nos. DOT-TSC-(RA)-76-10, DOT-FA77WA-4039, DOT-FA77WAI-720 and DTFA01-81-C-10117). Another major effort was on stratospheric-tropospheric exchange processes, based on all available radiosonde data, to improve two-dimensional parameterization of transport phenomena (Contract Nos. DOT-FA77WA-3992 and DTFA01-80-Y-10558). Diffusion of aircraft exhaust at cruise altitudes and the atmospheric mechanisms of its interaction with the ambient atmosphere (Contract No. DOT-FA77WA-4055), causes for the local variability of trace species (Contract No. DOT-FA79WA-4306), studies of aircraft engine exhaust impacts on climate (Contract Nos. DOT-FA78WAI-9:1, DTFA01-80-C-10101 and DTFA01-80-Y-10573) and on tropospheric ozone (Contract No. AIA/CA-23), and an analysis of the uncertainty associated with the assessment of the impacts of aircraft engine exhaust on atmospheric ozone (Contract No. DTFA01-81-Y-10538) were the other important studies carried out under this program element.

V. CURRENT UNDERSTANDING OF THE EFFECTS OF AIRCRAFT ENGINE EMISSIONS ON THE UPPER ATMOSPHERE

The above scientific considerations can be summarized as follows:

1. From about 15 to 50 km (50,000 to 165,000 feet), NO_x can catalytically destroy ozone. The lower boundary is model-dependent and is determined by the details of chemical rate coefficients, numerical values of transport parameters and rainout/washout prescriptions. New data on any of these can alter the location of the lower boundary.

2. In the presence of at least 10 ppt of NO, oxidation of CO and CH_4 will create ozone; for the concentrations that are present in today's atmosphere, CO oxidation appears to be the dominant process (20).

CO can and does penetrate to lower stratospheric altitudes through mechanisms such as the tropical Hadley branch, and NO has been observed, at concentrations above 10 ppt, from about 12 km to about 65 km (see, for example, 8). Thus, even though one would expect ozone formation to continue into the stratosphere, it effectively ceases above about 15 km (this height is again model-dependent). This is because: (1) ozone molecules begin to outnumber CO and NO molecules above the tropopause; (2) the OH radical, instead of reacting with CO to form O_3, reacts with the more abundant O_3 leading to the latter's loss ($OH + O_3 \rightarrow H_2O + O_2$); (3) even if some OH reacts with CO to lead to HO_2 formation ($CO + OH \rightarrow H + CO_2$; $H + O_2 + M \rightarrow HO_2 + M$), the HO_2 thus formed reacts with the more abundant 03 rather than with NO, again leading to ozone loss ($HO_2 + O_3$ $OH + 2\ O_2$). The NO freed from its reaction with HO_2, reacts with the more abundant O_3 yielding NO_2 and O_2 (partial loss of ozone, since NO_2 can photolyze and ozone can be formed as a result).

3. It becomes obvious from an inspection of the chemical equations listed in Chapter II, that the NO_x, ClO_x and HO_x species not only affect the abundance of atmospheric ozone, but that they also interact among themselves (e.g., HO_2 + NO, ClO + NO_2). Thus, a change in the concentrations of any of them, resulting from human intervention, would affect the calculated impacts on ozone of the others. For example, changes in ClO (from changing chlorofluoromethane concentrations) will necessarily interfere with NO_2 concentrations, and vice versa. Hence, any believable model calculation will have to consider simultaneous changes in all man-made perturbations to the upper tropospheric-to stratospheric properties. Changes in concentrations of odd-chlorine, odd-hydrogen and odd-nitrogen species, and in the radiatively active gases such as CO_2 (because of the feedback between temperature change and ozone abundance), all must be considered together. Any future scenario would have to incorporate in an appropriate manner projected changes in these species.

Aircraft NO_x Emissions:

Almost all the NO_x (about 95%) is emitted as NO by aircraft engines. For maintaining historical continuity with CIAP calculations and for readily comparing results with each improvement in modeling, calculations of ozone change have been made by the FAA for assumed injections of NO_x at various altitudes. If a cause for concern arises, then of course detailed calculations for any given fleet can be carried out.

One NO_x injection rate assumed is 1000 molecules of NO per second per cubic centimeter over a 1-km height range centered at 7, 9, 11, 13, 15, 17 and 20 km altitudes. The last two altitudes were chosen as representative of current and possible future supersonic fleet cruise levels. If all the NO_x is assumed to be injected in the Northern Hemisphere--which to a first approximation represents the present state of affairs--this assumed rate of NO_x injection is equivalent to 397 million kilograms (872 million pounds) of NO being added to the atmosphere annually and thus quite large; it can be translated to various fleet sizes depending upon the fuel burn rate, engine emission index for NO_x and aircraft utilization. The NO_x emission index is the number of grams of NO_x, measured and expressed more conveniently in equivalent NO_2 amounts, emitted per kg of fuel burned. An injection rate of 1000 NO molecules per second per cubic centimeter spread over a 1-km thick layer is also equivalent to 608 million kg (or 1.34 billion pounds) of NO_2 per year.

To put this injection rate in perspective, consider the following illustration: following the same specifications used by CIAP, a four-engine wide-body airplane consuming 10,200 kg of fuel per hour, cruising at altitude for 5.4 hours every day of the year, and emitting 15 gm of NO_2 per kg of fuel consumed, will inject 302,000 kg or (663,000 pounds) of NO_x per year to the atmosphere. A "Concorde-like" civilian supersonic transport with a fuel burn rate of 19,100 kg per hour, cruising 4.4 hours every day of the year and with an emission index of 18 gm of NO_2 per kg fuel burned will add 552,000 kg (or 1.21 million pounds) of NO_2 to the atmosphere annually. Thus, the NO_x injection rate assumed for model calculations is the same as would be emitted by a fleet of about 2,000 four-engine wide-body airplanes or by a fleet of about 1,100 "Concorde-like" SST's (with the assumed specifications given above).

An appreciation of the magnitude of the above injection rate can also be obtained in another way. One of the fleet projections (for a reasonably optimistic economic scenario) and the resulting NO_x emissions made for the High Altitude Pollution Program (21, 22, 23, 8) showing the injections at various altitudes for the year 1990 is reflected in Table 3.

Even though the total NO_x injection projected is quite large, it must be remembered that its height distribution is such that almost all of it (about 97%) takes place in the region where ozone generation due to NO_x presence dominates the odd-nitrogen catalytic removal mechanism.

Considerations of fuel efficiency generally lead to higher-pressure-ratio engines and these engines operating at higher temperatures are likely to emit more NO_x. Hence, it is not clear whether improved fuel efficiency, while reducing the number of kg of fuel used, may not leave NO_x emissions at cruise altitudes unchanged, or even increased somewhat, due to a larger NO_x emission index.

Results of Model Calculations:

Table 4, below summarizes the current calculations of total ozone changes for NO_x injections at various altitudes. The ozone changes are given for three different injection rates.

It may be seen from the table that for injections below 13 km, total ozone increases, while for injections above this altitude it decreases. The magnitude of the injection is important with larger injections leading to larger increases below 13 km and to larger decreases above that altitude. Also, ozone change seems to be a linear function of the NO_x injection rate (see figures 2 and 3). For actual or projected fleets where the injection is distributed over a large height range, the ozone change has to be calculated for each case.

% Total O_3 Change
NO Injection

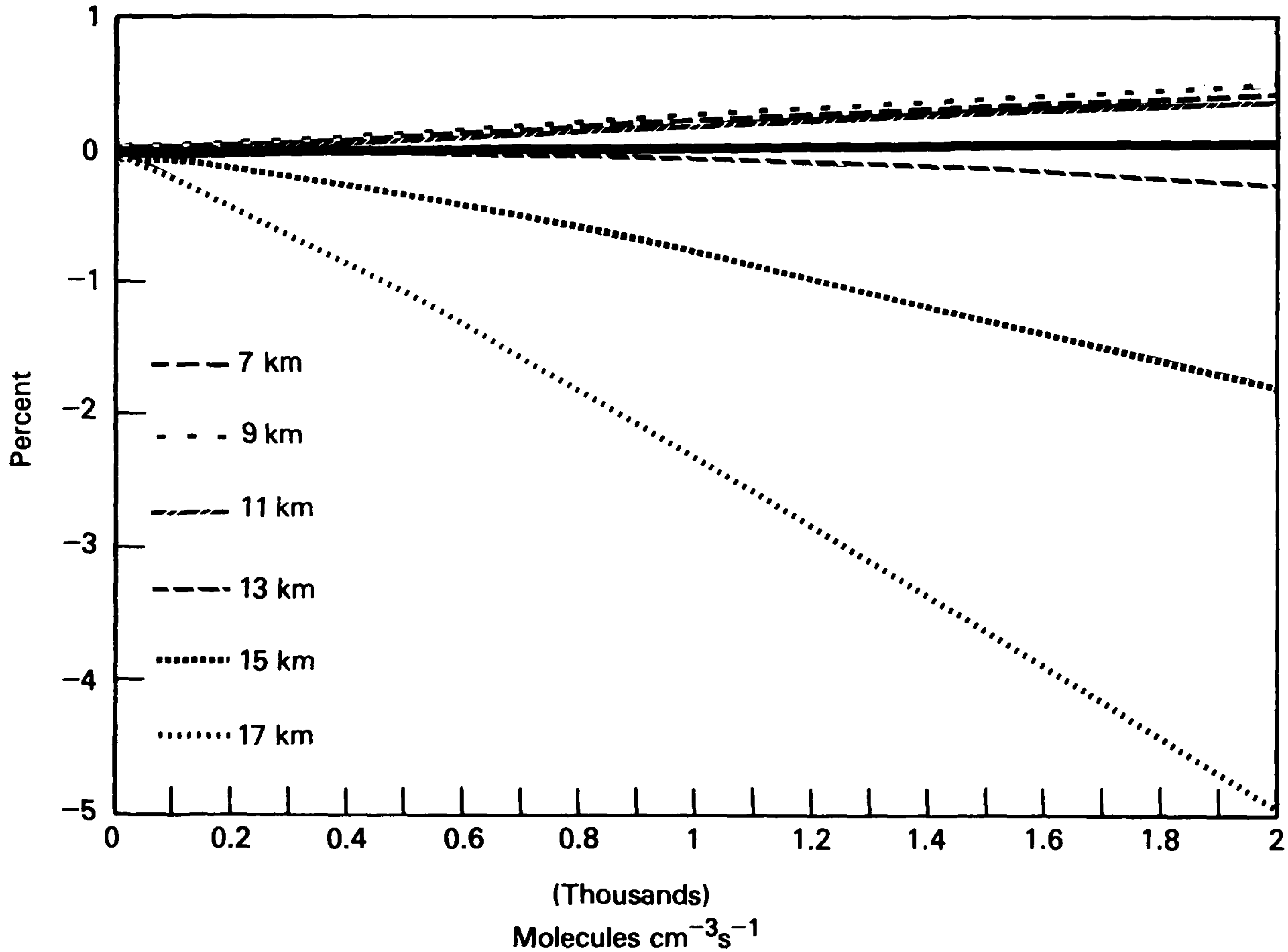

Figure 2

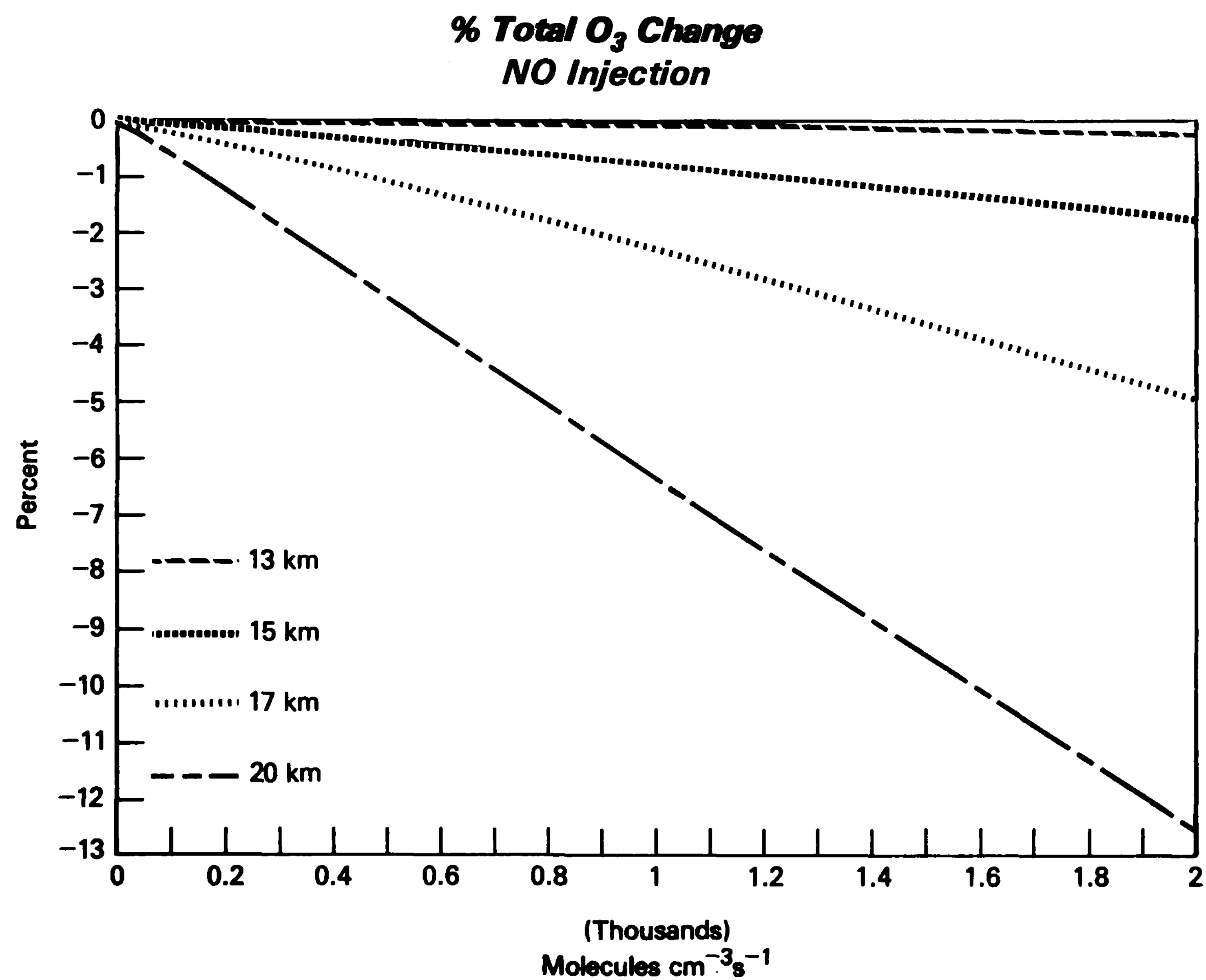
% Total O_3 Change
NO Injection
Percent
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
−11
−12
−13
13 km
15 km
17 km
20 km
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
(Thousands)
Molecules $cm^{-3}s^{-1}$

Figure 3

TABLE 3

ONE HAPP-PROJECTED SCENARIO FOR NO_x EMISSIONS IN 1990
(NORTHERN HEMISPHERE)

INJECTION ALTITUDE (KM)	NO_x Injection Rate *	
	NO	NO_2
6	90	54.7
7	179	109.0
8	265	161.0
9	665	404.0
10	1167	710.0
11	1161	706.0
12	520	316.0
13	75	45.6
14	18 **	10.9
15	18	10.9
16	33	20.1
17	43	26.1
18	28	17.6
19	8	4.9
TOTAL	4271	2596.8

Figures 4, 5 and 6 illustrate the altitude profile of ozone concentration change (%) for NO_x injections of 500, 1000 and 2000 molecules (NO) per cubic centimeter per second spread over a 1-km thick layer centered at 7, 9, 11, 13, 15, 17 and 20 km altitudes. It may be seen from these figures that for all injection altitudes other than for 20 km, ozone generation occurs at lower altitudes while ozone decrease occurs above. The sum total of the ozone change is the quantity listed in Table 4. Ozone production at lower altitudes and its loss at higher altitudes gives rise to a perturbation in the ozone concentration profile, regardless of whether total ozone changes or not.

Decreases in total ozone are a matter of concern, since they lead to increased solar radiation in the biologically harmful wavelengths and hence to increased skin cancer incidence. A decrease of 1 percent in total ozone will, roughly, lead to a 2 percent increase in skin cancer

* NO is in units of molecules per cubic centimeter per second; NO_2 is in units of millions of kg per year.

** Emissions from the projected 1990 SST fleet are included at 14 km and above.

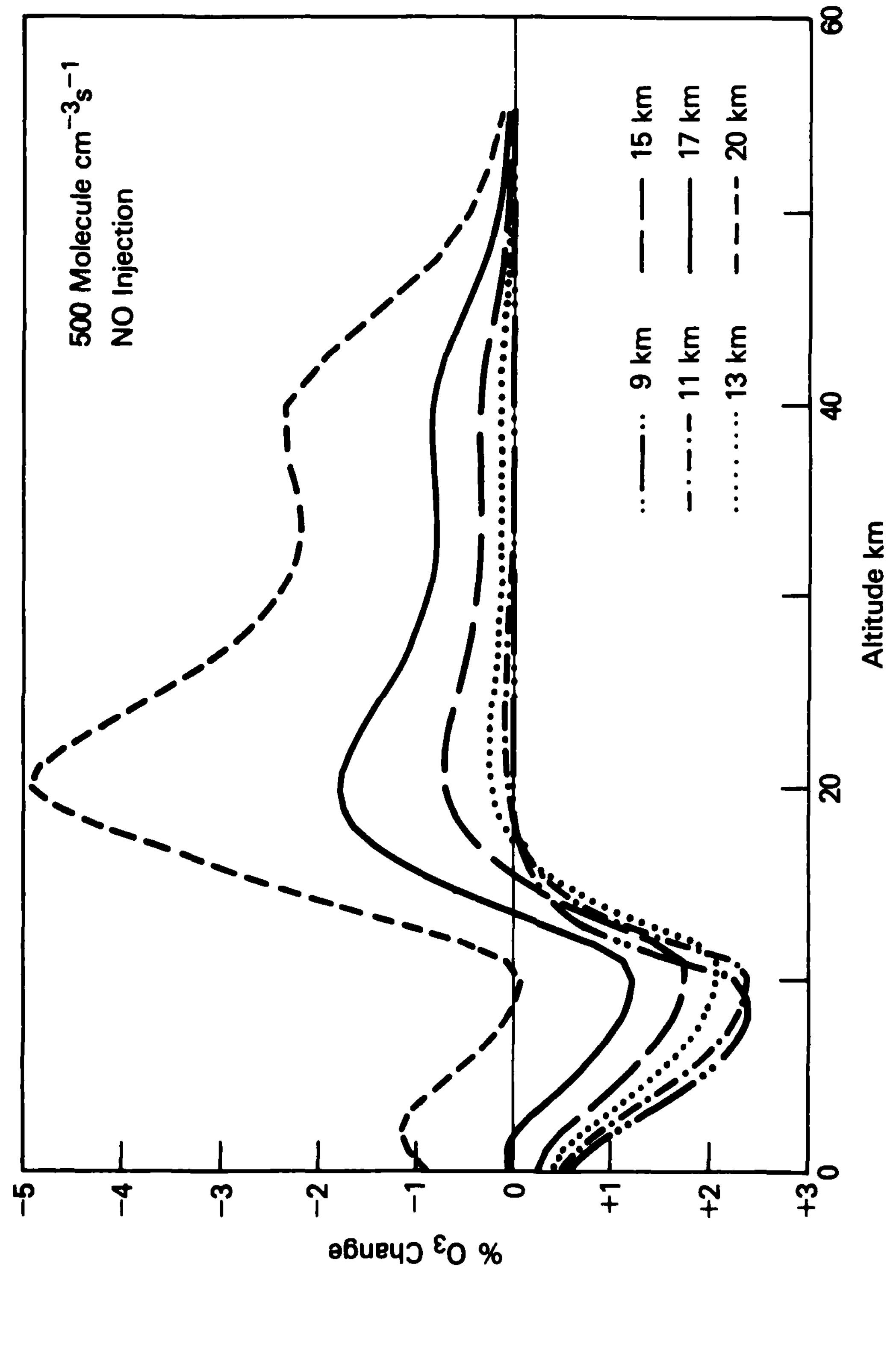
500 Molecule $cm^{-3}s^{-1}$
NO Injection
9 km
11 km
13 km
15 km
17 km
20 km
% O_3 Change
−5
−4
−3
−2
−1
0
+1
+2
+3
0
20
40
60
Altitude km

Figure 4

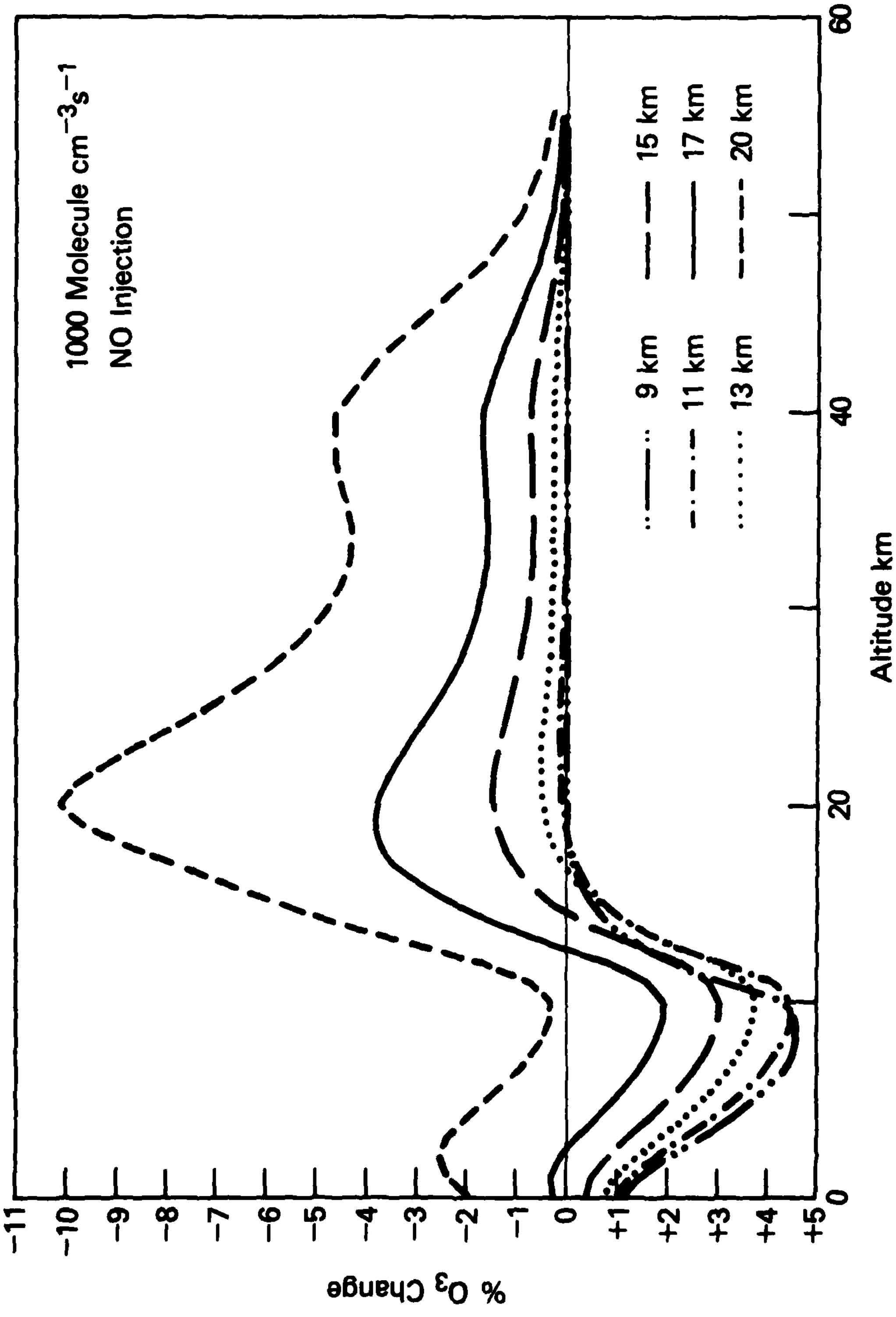
1000 Molecule cm^{-3}s^{-1}
NO Injection
9 km
11 km
13 km
15 km
17 km
20 km
% O_3 Change
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
0
20
40
60
Altitude km

Figure 5

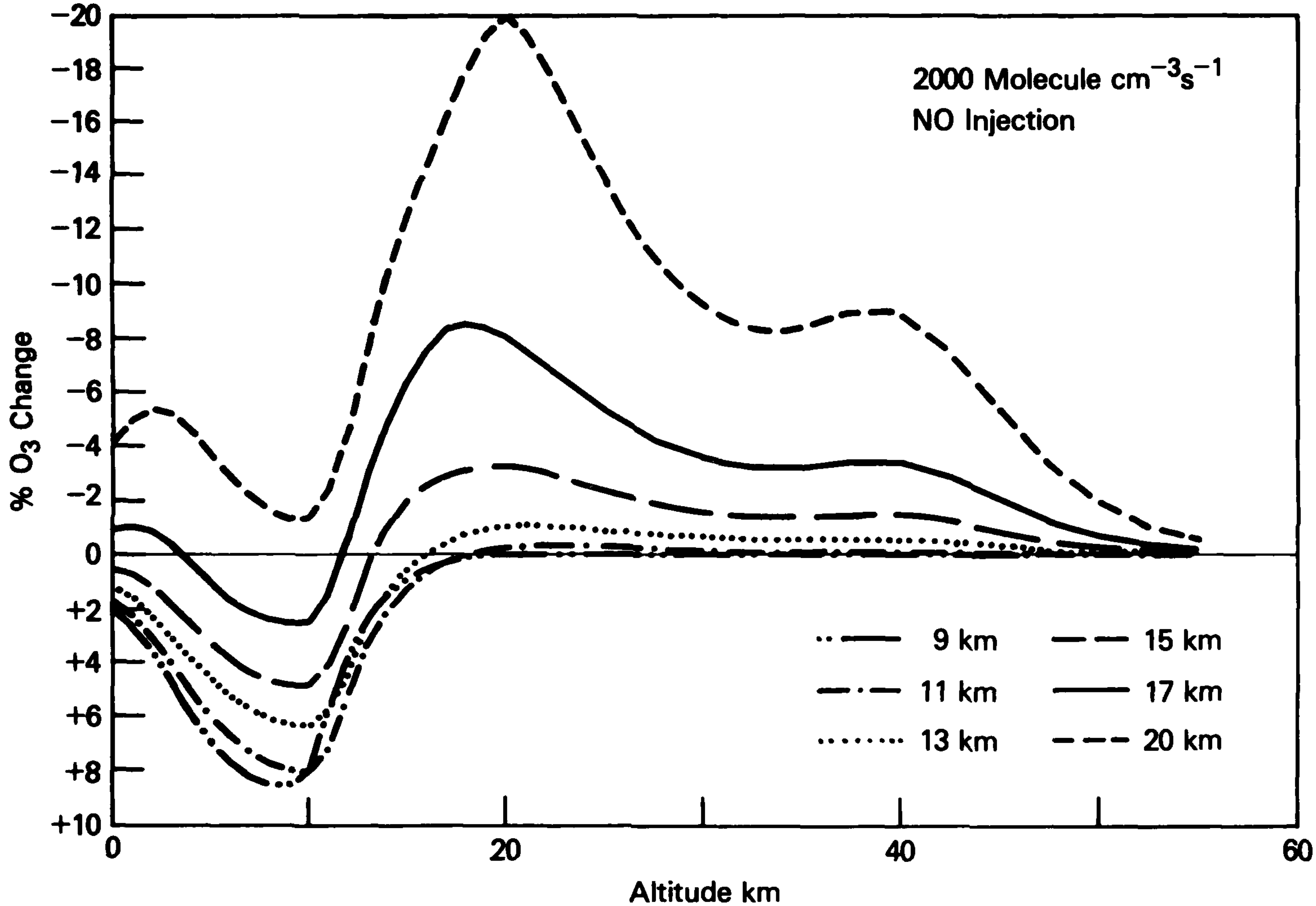
2000 Molecule cm^{-3}s^{-1}
NO Injection
9 km
11 km
13 km
15 km
17 km
20 km
% O_3 Change
Altitude km
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
+2
+4
+6
+8
+10
0
20
40
60

Figure 6

TABLE 4

CHANGE IN TOTAL OZONE (%) FOR VARIOUS NO_x INJECTIONS AT VARIOUS ALTITUDES

INJECTION ALTITUDE (KM)	NO INJECTION (molecules per cubic centimeter per second)		
	500	1000	2000
7	+0.11	+0.21	+0.40
9	+0.13	+0.25	+0.46
11	+0.12	+0.21	+0.35
13	-0.003	-0.065	-0.29
15	-0.34	-0.78	-1.80
17	-1.08	-2.32	-4.96
20	-3.14	-6.37	-12.52

incidence (1). Ozone profile changes, even if total ozone changes little, are a matter of concern because of possible ensuing changes in the greenhouse effect. Most recent calculations show that a 50 percent increase in tropospheric ozone, for example, will lead to a warming of the mean surface temperature of the earth by 0.3 degree Celsius or about 0.5 degree Fahrenheit (24); calculations for a nominal doubling of CO_2, likely perhaps in the third quarter of the next century, indicate a global warming of between 1.5 and 4.5 degrees Celsius (25). Preliminary trend analysis with available balloon ozonsonde data raise the possibility of tropospheric ozone increasing at the rate of about 0.7% per year within the last decade (24); what part, if any, of this trend is attributable to aircraft emissions is not an easy matter to decide.

Evolution of the Understanding of Aircraft Engine Emissions Impact on the Upper Atmosphere:

The most recent calculation mentioned above may be compared with the results of past calculations (see Table 5).

As chemical and transport data are refined, the evaluations of the impacts change, in keeping with the evolution of knowledge still going on in stratospheric science.

TABLE 5

EVALUATIONS OF EXPECTED TOTAL OZONE CHANGES FOR NO INJECTION OF 2000 MOLECULES PER CUBIC CENTIMETER PER SECOND SPREAD OVER 1-KM THICK LAYER CENTERED AT 17 AND 20 KM

DATE OF EVALUATION	TOTAL OZONE CHANGE (%) 17 KM	20 KM	COMMENTS
Mid-1974	-4.8	-10.2	CIAP calculation
Early 1975	-5.3	-11.2	minor chemical changes
Mid-1975	-4.3	-9.8	fast OH + HO_2
Mid to late 1975	-1.8	-5.2	slow OH + HO_2
Late 1975	-1.1	-3.5	$NO_3 + E \rightarrow NO_2 + O$
Mid-1976	-0.7	-2.9	minor chemical changes
Mid to late 1976	-0.7	-3.3	chlorine added
Mid-1977	-1.3	-4.8	minor chemical changes slow HO_2 + NO
Mid to late 1977	+2.0	+0.5	HO_2 + NO
Mid 1978	+3.2	+3.6	modified $HO_2 + O_3$ increased chlorine
Early 1979	+2.6	+2.2	minor chemical changes
Mid-1979	+2.0	+1.1	minor chemical changes
Early 1980	+1.7	+0.6	minor chemical changes
October 1980	-0.3	-4.5	new OH + HNO_3
December 1980	-0.7	-5.3	minor chemical changes
May 1981	-2.2	-7.1	fast OH + HO_2NO_2
January 1984	-4.96	-12.5 2	improved transport

Results of Calculations for the HAPP-Projected 1990 Fleet:

To illustrate a fleet scenario, calculations have been made for the HAPP-projected 1990 fleet listed in Table 3. The total ozone increases by 0.31 percent, if this fleet were to remain unchanged and flying forever. This may be compared against earlier calculations for the same fleet: 2.0 percent in 1979 and 1.2 percent in 1981. The tropospheric ozone shows an increase of 15 percent while stratospheric ozone shows a decrease of 1 percent, the net change in atmospheric ozone being 0.31 percent. Assuming a tenth of the total atmospheric ozone to reside in the troposphere, the calculated increase in tropospheric ozone amounts to 1.5 percent in the steady state.

From the previous discussion it would appear that there is no immediacy of concern with regard to ozone and climatic changes that may result from the operations of civilian aircraft.

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APPENDIX A

HAPP CONTRACTS REFERRED TO IN PART IV

UNDER "MAJOR HAPP ACCOMPLISHMENTS"

ENGINE EMISSIONS

(1) DOT-FA77WA-3066 — Analysis of Fuel Usage
Eastern Airlines

P. Zegan — August 1977 to October 1978

For input to improve forecasts of emissions loading for use in model calculations, to compile forecasts of fuel burn by geographic location and altitude based on aircraft fleet projections through the year 2000.

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(2) DOT-FA75WA-3574 — International Air Traffic Forecast
SRI International

R. Pozdena — January 1976 to September 1976

To produce a world aviation forecast for long-range, high-altitude flights for the years 1975 to 1990 (five year intervals) by aircraft equipment and fleet.

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(3) DOT-FA76WAI-603 — Stratospheric Emissions from Aircraft Operations
Environmental Protection Agency/
A. D. Little Co.

P. Athens — February 1976 to August 1976

For subsequent use in studies of stratospheric impacts and possible need for aircraft regulations, to determine emission indices for aircraft engines operating above 8 km and provide global emissions loading data.

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(4) DOT-FA76WA-3757 — Assessment of Stratospheric Effects and Uncertainties
Institute for Defense Analyses

R. Oliver — October 1975 to August 1976

To review the Report of Findings of the DOT/CIAP and other documents concerning stratospheric ozone depletion and to assess effects of high-altitude aircraft on the environment.

---

(5) DOT-FA77WAI-4081 — Nitric Oxide Measurement Study

United Technologies Research Center

M. F. Zabielski — September 1977 to May 1980

Investigate both optical and sample-extractive methods for measuring nitric oxide in combustion systems and define and document the difference between the results from the two methods.

---

(6) DTFA01-82-Y-10505 — Global Aviation Emissions Forecast

ATAC Inc.

J. Bobick — December 1981

Modify Global Aviation Forecast Model to expand its capabilities to include projections of aircraft engine emissions at various altitudes and geographic grid locations.

LABORATORY MEASUREMENTS

(1) DOT-TSC-1201
Ford Motor Company

Laboratory Study of Chemical Reactions

E. Kaiser

June 1976 to June 1977

To study the rate of the reaction of HONO + O_3 and $O(^3P) + N_2O_5$.

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(2) DOT-TSC-1203
York University

Laboratory Study of Chemical Reactions

H. Schiff

June 1976 to December 1978

To determine the reaction rates and products of $O(^1D) + N_2O$ and of $O(^3P) + N_2O_5$.

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(3) DOT-TSC-1200
AeroChem Research Laboratories

Measurements on $O(^1D)/N_O$ and HNO_2/O_3 Kinetics

A. Fontijn

June 1976 to June 1977

To measure the branching ratio of $O(^1D) + N_2O$ and the products of the reaction HONO + O_3 over stratospheric temperatures.

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(4) DOT-FA78WA-4262
Xonics, Inc.

Measurement of the Rate of OH + ClO

R. A. Young

September 1978 to February 1980

To determine the rate of reaction of OH with ClO as a function of temperature and pressure.

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(5) DOT-FA79WAI-112
Department of Commerce/NBS

Study of the Mechanism of Reaction of OH with HO_2

M. Kurylo

November 1979 to February 1981

To investigate the mechanisms of OH + HO_2 using isotopic labeling kinetic studies.

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(6) DTFA01-80-Y-10559
NASA/Goddard Space Flight Center

Measurement of the Rate of Reaction of Nitric Oxide (NO) with Ozone (O_3)

J. Allen

May 1980 to May 1981

To investigate the temperature dependence of the $NO + O_3$ reaction rate using three different experimental procedures.

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(7) DOT-FA78WA-4228
SRI International

Measurement of Reaction Rates for Pernitric Acid with OH and $O(^3P)$

J. R. Barker

September 1978 to June 1981

To determine the rate of reaction of OH and $O(^3P)$ with HO_2NO_2 as a function of temperature.

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(8) DOT-FA79WA-4393
Pennsylvania State University

Direct Determination of the Reaction of CH_3O_2 with NO

J. Heicklen

September 1979 to June 1981

To measure the rate and temperature dependence of the reaction of methyl peroxy radicals with nitric oxide.

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(9) DOT-FA78WA-4259
Georgia Tech Research Institute

Measurement of the Rate of $CH_3O_2 + NO_2$

P. H. Wine/A. R. Ravishankara

September 1978 to November 1981

To measure the rate of $CH_3O_2 + NO_2$ over the relevant range of tropospheric temperatures and pressures.

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(10) DOT-FA79WA-4362 — Smithsonian Institution Astrophysical Observatory — Direct Determination of the Rate of Reaction of Methoxy Radicals (CH_3O) with Molecular Oxygen and Ozone

H. Radford — September 1979 to December 1981

To measure the rate of reaction to methoxy radicals with oxygen and ozone by means of a laser magnetic resonance apparatus.

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(11) DOT-FA77WA-4054 — University of Cambridge — Measurement of Perhydroxyl Reaction Rates

B. Thrush — September 1977 to June 1982

To measure the absolute rate and temperature dependence of the reactions of HO_2 with HO_2, OH, SO_2, Cl, NO, O_3, Br, and H.

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(12) DTFA01-80-C-10084 — University of California at Irvine — Measurement of Hydroxyl Radicals' Reaction with Hydrogen Peroxide

M. Molina — July 1980 to July 1982

To measure the rate of reaction of hydroxyl radicals with hydrogen peroxide using flash photolytic production of OH and showing an unequivocal determination of the concentration of hydrogen peroxide at all stages of the reaction.

---

(13) DOT-TSC-1204 — SRI International — NO_2 Photolysis

J. Davenport — June 1976 to June 1977

To measure the NO_2 photolysis cross-sections and quantum yields between wavelengths 385 to 425 nm and temperatures 200-300K.

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(14) DOT-FA78WA-4248
University of California at Irvine

Measurement of the Photolytic Parameters for Pernitric Acid

M. Molina

September 1978 to February 1980

To determine the cross section in the UV and IR for HO_2NO_2 and to deduce quantum yields for its photolytic decomposition.

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(15) DOT-FA78WA-4263
SRI International

Measurement of the Photolytic Parameters for O_3

J. Davenport

September 1978 to May 1980

To determine the cross section and quantum yields for O_3 photolysis over the threshold region.

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(16) DOT-FA78WA-4264
Max-Planck Institute

Measurement of the Photolytic Parameters for Formaldehyde

P. Warneck

September 1978 to November 1980

To measure the absorption cross section and quantum yields for HO_2CO as a function of temperature and pressure.

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(17) RA 76-13-6400223
Department of Commerce/NBS

Reaction Rate Data, Tabular Input

D. Garvin

January 1976 to May 1978

This effort includes the following:

1. Review of Atmospheric Rate Constant Data
2. Compilation of $ClONO_2$ Kinetic Data
3. Compilation of Combustion Kinetic Data

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(18) DOT-FA79WAI-005
Department of Commerce/NBS

Evaluation of Chemical Reaction Rate Data and Photochemical Data for Atmospheric Modeling

R. Hampson

December 1978 to March 1980

To prepare detailed evaluations of NO_x and $O(^1D)$ reactions and to compile an evaluation of all other atmospheric reactions in individual data sheet form.

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(19) DTFA01-80-Y-10532
Department of Commerce/NBS

Evaluation of Kinetics and Photochemical Data for Atmospheric Modeling

R. Hampson

April 1980 to June 1981

To update and maintain an evaluation of the chemical reaction rates and photochemical paramteres required as the data base for atmospheric models used for the assessment of aircraft effects on the environment.

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(20) DTFA01-81-Y-10519
Department of Commerce/NBS

Evaluation of Kinetics and Photochemical Data for Atmospheric Modeling

R. Hampson

May 1981

To update and maintain an evaluation of the chemical reaction rates and photochimical parameters required as the data base for atmospheric models used for the assessment of aircraft effects on the environment.

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(21) DOT-FA78WAI-859
Department of Energy/
Brookhaven National Laboratory

Investigation of Tropospheric Rainout Process

S. Schwartz

May 1978

To review available literature addressing the chemistry of the interaction of nitrogen oxides and oxyacids with atmospheric water. As a result of the review, to perform necessary modeling, laboratory measurements, and field measurements to define the tropospheric rainout removal process.

FIELD MEASUREMENTS

(1) W1-78-3745-1 — Trace Gas Analysis of Concorde Air Samples

Oregon Graduate Center for Study and Research

R. Rasmussen — April 1978 to October 1978

To participate in analysis of Concorde air samples and compare with data obtained on same species during previous high altitude flights. Also to evaluate the sampling program and describe needs to obtain the maximum scientific knowledge from the program.

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(2) DOT-FA79WA-4285 — Concorde Whole Air Sampling

Oregon Graduate Center for Study and Research

R. Rasmussen — February 1979 to November 1981

To conduct whole air sampling on not less than 10 Concorde flights between Dulles and Heathrow. Perform trace gas analysis on these samples and compare results with data previously obtained.

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(3) DOT-FA77WAI-748 — Measurement of Stratospheric H_2O

Naval Research Laboratory

J. Mastenbrook — June 1977

To design, develop and test a frostpoint hygrometer-type instrument to measure atmospheric water vapor. To continue periodic water vapor measurements presently conducted by NRL and compare data obtained for a period of one year with soundings in the vicinity of Boulder, Colorado.

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(4) DTFA01-80-Y-10568 — Measurement of Atmospheric H_2O; NO_2; CO; H_2O_2 by Dissociative Flourescence and Resonance Flourescence

NOAA/Aeronomy Laboratory

D. Kley — July 1980

To develop and perform balloon flight test of a daytime and nighttime ultraviolet fluorescence water vapor instrument, a resonance fluorescence CO instrument, and dissociative fluorescence NO_2 and H_2O_2 instruments.

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(5) DOT-FATQWAI-684
National Science Foundation/
National Center for
Atmospheric Research

Measurement to 45 Kilometers Using Cryogenic Sampling and Other Techniques

L. Heidt

October 1976

To conduct four (2 at the equator and 2 at northern latitudes) atmospheric balloon and aircraft cryogenic sampling missions and provide data analysis.

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(6) W1-78-3740-1
Dr. Rudolph Penndorf

Analysis of Ozone and Water Vapor Field Measurement Data

R. Penndorf

April 1978 to December 1978

To review and update results obtained for ozone and water vapor data under contract DOT-FATQWA-3866.

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(7) DOT-FA78WA-4232
Harvey Mudd College

Development of H_2O_2 Measurement Instrumentation

G. Kok

September 1978 to June 1981

To develop instrumentation for the in situ measurement of gas phase hydrogen peroxide in the stratosphere and upper troposphere for concentrations from 0.1 ppbv to 100 ppbv.

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(8) DOT-FA76WAI-648
Department of Defense/
Office of Naval Research

Balloon Launch, Tracking, and Recovery Costs for NO Detector Flight to 45 km

Commander W. Smith

June 1976 to October 1976

To provide flight services in connection with a balloon launch conducted by the University of Wyoming to detect nitric oxide up to an altitude of 45 km.

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(9) DOT-FA77WA-3949
University of Denver

Data Interpretation of Measurements of Trace Gases

D. Murcray

February 1977 to August 1978

To determine the error in deducing NO and NO_2 altitude profiles from infrared solar spectra obtained at high altitudes during sunrise and sunset.

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(10)	DOT-FA77WA-3931 York University	In Situ Measurements of NO, NO_2 and N_2O_5 in the Stratosphere from Balloons
	H. Schiff	January 1977 to November 1979

To perform four balloon flights to make simultaneous NO, NO_2 and if obtainable N_2O_5 measurements throughout the course of a day. Also, to investigate laser diode technology for measurement of NO and NO_2 to better than 100 pptv.

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(11)	DOT-FA77WAI-722 NASA/Langley Research Center	Development of Advanced Instrumentation Tunable Double Heterostructure Laser Diodes
	F. Allario	February 1977 to June 1980

Using molecular beam epitaxy techniques, to grow laser fibers, to fabricate lasers from these fibers and test for device characterization.

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(12)	DOT-FA77WA-4080 Perkin-Elmer Corporation	Development of Stratospheric Measurement System
	N. Macoy	September 1977

To perform a feasibility study to provide a conceptual design with documentation for an instrument to simultaneously measure the odd nitrogen species in the stratosphere. To perform necessary laboratory measurements to verify the critical parts of the measurement system and fabricate a laboratory prototype measurement system to demonstrate feasibility.

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(13)	DTFA01-80-Y-10565 NOAA/Aeronomy Laboratory	NO, NO_2 and Total Odd-Nitrogen Stratospheric Balloon Flights
	M. McFarland/D. Albritton/ A. Schmeltekopf	June 1980

To perform necessary laboratory studies to develop a stratospheric balloon-borne instrument using chemiluminescent/photolytic techniques to measure NO and NO_2 and pyrolytic conversion to measure N_2O_5, HNO_3 and other odd-nitrogen species. After successful development to perform at least eight balloon flights at high, mid and low latitudes during both the summer and winter.

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(14) DTFA01-80-C-10039
University of Denver

Infrared Data Analysis and N_2O_5 Balloon Flight

D. Murcray

March 1980 to April 1982

To use high resolution sunset solar absorption data to determine ozone line parameters for the ν_1 and ν_3 fundamental bands as well as the hot bands of ozone, and to perform a dedicated balloon flight using an emission spectrometer to detect the presence of N_2O_5 in the stratosphere.

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(15) AIA/CA-13
Memorandum of Agreement with the Canadian Atmospheric Environment Service

International Development and Flight Test of a Balloon-Borne Tunable Laser Diode Spectrometer System for Stratospheric Measurements

W. Evans/H. Schiff/B. Ridley

October 1978

To develop a tunable laser diode spectrometer to measure at least NO and NO_2 in the stratosphere and perform a flight test of the instrument.

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(16) AIA/CA-17
Memorandum of Understanding with the Australian Commonwealth Scientific and Industrial Research Organization

Comprehensive Set of Trace Gas Measurements in the Southern Hemispheric Stratosphere

I. Galbally

February 1979

To perform six balloon flights to obtain stratospheric measurements including latitudinal, altitudinal, and seasonal and (if possible) diurnal variations of nitrous oxide, nitric oxide, nitrogen dioxide and nitric acid along with ozone, water vapor, CFM's and air temperature in the Southern Hemisphere.

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(17) DOT-FATQWAI-653
Department of Energy/
Lawrence Livermore Laboratory

Numerical Simulation and Ozone Data Analysis

F. Luther

July 1976 to September 1978

To continue model refinement started under DOT-TSC-(RA)-76-1 with improved tropospheric chemical cycles. Also, to process ozone data obtained from the USAF Block 5-D satellite and perform global data analysis.

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(18) DOT-FA78WAI-850
NOAA/Environmental Research Laboratory

Analysis and Intercomparison of Ozone Measurements from Dobson Instruments

W. Komhyr

January 1978 to December 1982

To reprocess total ozone data collected over the past 15 years from the 15 station NOAA Dobson spectrophotometer network. To maintain the world standard calibration instrument and provide calibration for instruments at other stations.

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(19) AIA/CA-12
Memorandum of Agreement with the World Meteorological Organization

International Intercomparison of Rocketborne Ozonesondes

R. Bojkov

September 1978

To implement an international intercomparison of rocketborne ozonesondes at the NASA/Wallops Flight Center Facility in August-October 1979.

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(20) DOT-FA78WAI-860
Department of Energy/Los Alamos Scientific Laboratory

Investigation of a Global Transport Experiment

P. Guthals

March 1978 to February 1980

To examine possible tracers for a global transport experiment and include considerations of their chemistry and instrumentation for sample collection. Also, to review the scientific value of such an experiment.

MODELING

(1) DOT-TSC-(RA)-76-1
Department of Energy/
Lawrence Livermore Laboratory

Numerical Simulation of Atmospheric Response

F. Luther

August 1975 to June 1976

To refine the LLL one-dimensional model for the stratosphere in the areas of photochemical kinetics, transport kinetics and radiation transfer.

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(2) DOT-FA79WAI-034
Department of Energy/
Lawrence Livermore Laboratory

Study of Atmospheric Modeling and DMSP Satellite Ozone Data

F. Luther

April 1979

To develop and maintain a state-of-the-art capability presently existing at LLL to numerically model all atmospheric phenomena relevant to HAPP requirements. Also, to receive and reduce ozone data sensed by the USAF Block 5-D satellite.

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(3) DOT-TSC-(RA)-76-10
USAF SAMSO/Aerospace Corporation

Latitude Variation in Ozone Reduction

G. Widhopf

September 1975 to December 1976

To refine the transport parameterization in the Aerospace two-dimensional model using available tracer data and use the refined model to compare predictions with actual distributions of atmospheric trace species.

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(4) DOT-FA77WA-4039
Colorado State University

Stratospheric Studies Using the Crutzen Two-Dimensional Model

P. Crutzen

September 1977 to August 1980

To refine the Crutzen model of the stratosphere and to use it to study trace species distributions, water vapor budget and the effects of high-altitude aviation on stratospheric ozone.

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(5) DOT-FA77WAI-720 — Two-Dimensional Model Studies
USAF SAMSO/Aerospace Corporation

G. Widhopf — December 1976 to April 1983

To continue to refine the Aerospace two-dimensional model to incorporate chlorine chemistry, multiple scattering, and to use the model to study the effect of high-altitude aviation on stratospheric ozone.

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(6) DTFA01-81-C-10117 — Assess the Effects of Cruise Altitude Flight on Ozone Utilizing the Crutzen Model
Max-Planck Institute for Chemie

P. Crutzen — October 1981 to January 1983

To modify the two-dimensional model developed originally by Dr. Paul Crutzen to conduct studies of aircraft effects on ozone. The model includes rainout phenomena, and stratospheric and tropospheric chemistry.

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(7) DOT-FA77WA-3992 — Stratospheric-Tropospheric Exchange Processes
Oregon State University

E. Danielsen — August 1977 to April 1980

To develop, test and document an objective metholology based on routinely available synoptic meterological data for the quantitative determination of stratospheric-tropospheric mass exchange. To use this methodology to determine all relevant transport parameters for use in two-dimensional models of the stratosphere.

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(8) DTFA01-80-Y-10558 — Two-Dimensional Transport Parameterization
NASA/Ames Research Center

E. Danielsen — April 1980 to September 1982

To derive representative mean meridional velocities and the components of a diffusion tensor for two-dimensional chemical-photochemical transport models to improve their reliability and accuracy.

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(9) DOT-FA77WA-4055 — Center for Environment and Man, Inc. — Atmospheric Mechanisms

G. Robinson — September 1977 to December 1979

In light of recent chemical kinetics data, to reexamine the chemistry and diffusion of aircraft exhaust trails and include interpretations of available trace species measurements and transport parameterizations.

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(10) DOT-FA79WA-4306 — Science Applications, Inc. — Assess the Nature of Local Variability of Trace Species of Stratospheric Importance

R. Gelinas — June 1979 to November 1981

To study the local variability of trace species concentrations so that their atmospheric measurements may be used to (a) verify one- and two-dimensional stratospheric models, (b) develop an improved stratospheric measurement strategy, and (c) estimate the probable range of inaccuracies inherent in present stratospheric ozone models.

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(11) DOT-FA78WAI-911 — National Science Foundation/ Climate Research Board — Study of Aircraft Effects on Climate

A. Hecht — September 1978 to August 1980

Through the Climate Research Board of the National Academy of Sciences, to assess the impact of high-altitude aviation on the climate.

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(12) DTFA01-80-C-10101 — Atmospheric and Environmental Research — Research on the Climate and Ozone Perturbations Related to Aerospace Activities

N. Dak Sze — September 1980

To study stratospheric ozone perturbations and possible climate effects associated with aircraft operations using the application of a specially constructed one-dimensional model which permits realistic interactions of radiative, chemical and dynamical processes.

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(13) DTFA01-80-10573
NOAA/Climate Research Board

Effects of Aircraft Emissions on Global Mean Temperature

R. Etkins

July 1980

Through the Climate Research Board at the National Academy of Sciences, to assess the impact of high-altitude aviation on the climate.

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(14) AIA/CA-23
Memorandum of Agreement with the Royal Norwegian Council of Scientific and Industrial Research

Model Evaluations of Ozone Changes which may be caused by Aircraft Operations

B. Landmark/I. Isaksen

January 1981

To perform calculations with the Isaksen-Hesstvedt model to evaluate the local ozone change occurring in the troposphere due to cruise-altitude aircraft emissions.

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(15) DTFA01-81-Y-10538
NASA/Goddard Space Flight Center

Ozone Uncertainty Analysis and Solar Flux Measurements

R. Stolarski

June 1981

To conduct an uncertainty analysis of predictions of ozone perturbations from aircraft NO_x emissions by propagating uncertainties of known chemical rate coefficients and solar flux through a one-dimensional stratospheric photochemical model by means of a Monte Carlo simulation. Solar flux irradiance measurements will also be reviewed and evaluated in order to assess the temporal variability of solar flux output as a function of wavelength.

APPENDIX B

BIBLIOGRAPHY OF REPORTS, PUBLISHED MATERIAL, AND ORAL PRESENTATIONS OF WORK SUPPORTED BY HAPP*

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*At the time this report went to press there were still some reports outstanding but this bibliography includes most of the studies to come out of the program.

AEROCHEM RESEARCH LABORATORIES

FAA Contract No.: DOT-TSC-1200 June 1976 to June 1977

Principal Investigator: Arthur Fontijn

Title: Measurements on $O(^1D)N_2O$ and H_2NO_2/O_3 Kinetics

Purpose: To measure the branching ratio of $O(^1D) + N_2O$ and the products of the reaction HONO + O_3 over stratospheric temperatures.

Publications:

Pirkle, Robert, J. Volltrarer, N. Hermann, William Felder, and Arthur Fontijn, Measurements on $O(^1D)/N_2O$ and HNO_2/O_3 Kinetics, FAA-EQ-77-10, June 1977, AeroChem Report No. TP-360.

Volltrayer, Hermann N., William Felder, Robert J. Pirkle, and Arthur Fontijn, "$O(^1D)/N_2O$ Branching Ratio at 290K," Journal of Photochemistry, Vol. 11, 1979, pp. 173-181.

AEROSPACE CORPORATION

FAA Interagency Agreement No.: DOT-TSC-(RA)-76-10 between Department of Transportation, Federal Aviation Administration, and U.S. Air Force (USAF), Space and Missile Systems Organization (SAMSO)

September 1975 to December 1976

Principal Investigator: George Widhopf

Title: Latitude Variation in Ozone Reduction

Purpose: To refine the transport parameterization in the Aerospace two-dimensional model using available tracer data and use the refined model to compare predictions with actual distributions of atmospheric trace species.

Publications:

Widhopf, George F., Leslie Glatt, and Raymond F. Kramer, "Potential Ozone Column Increase Resulting from Subsonic and Supersonic Aircraft NO_x Emissions," AIAA Journal, Vol. 15, 1977, pp. 1322-330.

AEROSPACE CORPORATION

FAA Interagency Agreement No.: DOT-FA77WAI-720 between Department of Transportation, Federal Aviation Administration, and U.S. Air Force (USAF), Space Missile Systems Organization (SAMSO)

December 1976 to April 1983

Principal Investigator: George F. Widhopf

Title: Two-Dimensional Model Studies

Purpose: To continue to refine the Aerospace two-dimensional model to incorporate chlorine chemistry, multiple scattering, and to use the model to study the effect of high-altitude aviation on stratospheric ozone.

Publications:

Glatt, L., and G.F. Widhopf, "Improved Two-Dimensional, Time-Dependent Transport Coefficients Using Distributions of Nuclear Debris in the Atmosphere," presented at the American Geophysical Union Spring Annual Meeting, April 1976.

Kramer, R.F., and G.F. Widhopf, "On Evaluation of Diurnally Averaged Photodissociation Rates in Atmospheric Photochemical Models," presented at the American Geophysical Union Spring Annual Meeting, April 1976.

____. "Evaluation of Daylight Averaged Photolytic Rate Coefficients in Atmospheric Photochemical Models." Journal of the Atmospheric Sciences, Vol. 35, No. 9, pp. 1726-1734, September 1978.

Widhopf, G.F., "A Phenomenological, Time-Dependent Two-Dimensional Photochemical Model of the Atmosphere," presented at the American Geophysical Union Spring Annual Meeting, April 1976.

Widhopf, G.F., and L. Glatt, "Numerical Modeling of Atmospheric Pollution," Proceedings of the Sixth International Conference on Numerical Methods in Fluid Dynamics held in Tbilisi, USSR, June 21-24, 1978; Lecture Notes in Physics, Vol. 90, Springer-Verlog, edited by H. Cabannes, M. Holt and V. Rusanov.

____. "Two-Dimensional Description of the Natural Atmosphere Including Active Water Vapor Modeling and Potential Perturbations due to NO_x and HO_x Aircraft Emissions, FAA-EE-79-07, Aerospace Report No. ATR-79 (4858) IND, April 1979; also presented at XVII General Assembly, International Union of Geodesy and Geophysics and the Commission on the Meterology of the Upper Atmosphere, Canberra, Australia, December 2-15, 1979.

AEROSPACE CORPORATION

FAA Interagency Agreement No.: DOT-FA77WAI-720 (cont)

Publications: (cont)

____. "The Aerospace Time-Dependent Two-Dimensional Photochemical Model of the Atmosphere," included in World Meteorological Organization Report, January 1980.

____. Two-Dimensional Description of Potential Perturbations to the Ozone Layer Due to NO_x and H_2O Aircraft Emissions, FAA-EE-84-11, January 1984.

Whitten, R., W., Borucki, I., Poppoff, L. Glatt, G.F., Widhopf, L.A. Capone, and C.A. Reigel, "Two-Dimensional Model Studies of the Effect of Supersonic Aircraft Operations on the Stratospheric Ozone Content," NASA Reference Publication 1064, February 1981.

CENTER FOR THE ENVIRONMENT AND MAN, INC.

FAA Contract No.: DOT-FA77WA-4055 September 1977 to December 1979

Principal Investigator: George D. Robinson

Title: *Atmospheric Mechanisms*

Purpose: In using recent chemical kinetics data, reexamine the chemistry and diffusion of aircraft exhaust trails and include interpretations of available trace species measurements and transport parameterizations.

Publications:

Robinson, George D., The Perturbation of Some Atmospheric Mechanisms by Emissions from Aircraft, FAA-EE-80-16, Center for Environment and Man Report No. 4232-667, November 1979, also presented at AGU Meeting, San Francisco, CA, December 1978.

____. "The Transport of Minor Atmospheric Constituents Between Troposphere and Stratosphere," Quarterly Journal of the Royal Meteorological Society, Vol. 106, 1980, pp. 227-253.

COLORADO STATE UNIVERSITY

FAA Contract No.: DOT-FA77WA-4039 September 1977 to August 1980

Principal Investigator: Paul J. Crutzen

Title: Stratospheric Studies Using the Crutzen Two-Dimensional Model

Purpose: To refine the Crutzen model of the stratosphere and to use it to study trace species distributions, water vapor budget and the effects of high-altitude aviation on stratospheric ozone.

Publications:

Crutzen, Paul J. and Louis T. Gidel, Refinement and Modification of the Crutzen Two Dimensional Photochemical Model of the Stratospheric Ozone Balance, FAA-EE-81-2, May 1980.

Fishman, J., V. Ramanathan, Paul J. Crutzen, and S. C. Liu, "Tropospheric Ozone and Climate," Nature, Vol. 282, 1979, pp. 818-820.

Fishman, J., W. Seiler and Paul Haagenson, "Simultaneous Presence of O_3 and CO Bands in the Troposphere," Tellus, Vol. 32, 1980, pp. 455-463.

Fishman, J., S. Solomon, and Paul J. Crutzen, "Observational and Theoretical Evidence in Support of a Significant In-situ Photochemical Source of Tropospheric Ozone," Tellus, Vol. 31, 1979, pp. 432-446.

Gidel, Louis T. and M. A. Shapiro, "General Circulation Model Estimates of the Net Vertical Flux of Ozone in the Lower Stratosphere and the Implications for the Tropospheric Ozone Budget," Journal of Geophysical Research, Vol. 85, No. 198, pp. 4049-4058.

____. "The Role of Clear Air Turbulence in the Production of Potential Vorticity in the Vincinity of Upper Tropospheric Jet Stream-Frontal Systems," Journal of Atmospheric Sciences, Vol. 11, 1979, pp. 2125-2138.

CONTROL DATA CORPORATION

FAA Contract No. DOT-FA77WA-3999 July 1976 to August 1977

Principal Investigator: A.D. Belmont

Title: Report on Ozone Distribution From Available Ozonesonde Data in North America

Purpose: Using available ozonesonde data in the North American region, calculate the mean ozone concentrations, and their standard deviations, as function of height, month and latitude.

Publications:

Wilcox, Robert W., and Arthur D. Belmont, Ozone Concentration by Latitude, Altitude, and Month, Near 80° W, FAA-AEQ-77-13, Final Report, August 1977.

CONTROL DATA CORPORATION

FAA Contract No. DOT-FA77WA-4074 September 1977 to January 1978

Principal Investigator: A.D. Belmont

Title: Guidelines for Flight Planning During Periods of High Ozone Occurrence

Purpose: To prepare a set of guidelines which can be used, in conjunction with existing or forecast synoptic conditions, by flight planners, airline pilots, and other users to minimize or avoid cruise in regions of high ozone concentrations.

Publications:

Belmont, Arthur D., Robert W. Wilcox, Gregory D. Nastrom, Dale N. Hovland and Denis G. Dartt, Guidelines for Flight Planning During Periods of High Ozone Occurrence, FAA-AEQ-78-03, Final Report, January 1978.

FORD MOTOR COMPANY

FAA Contract No.:	DOT-TSC-1201	June 1976 to June 1977
Principal Investigator:	E. W. Kaiser	
Title:	Laboratory Study of Chemical Reactions	
Purpose:	To study the rate of the reaction of HONO + O_3 and $O(^3P) + N_2O_5$.	

Publications:

Kaiser, E.W., and Steven M. Japar, "The Kinetics of the Gas Phase Reaction of Nitrous Acid with Ozone," Chemical Physics Letters, Vol. 52, July 1977, pp. 121-124; also published as FAA Report No. FAA-EQ-77-7.

____. "The Kinetics of the Gas Phase Reaction of $O(^3P)$ with N_2O_5," Chemical Physics Letters, Vol. 54, September 1977, pp. 265-268; also published as FAA Report No. FAA-AEQ-77-11.

GEORGIA INSTITUTE OF TECHNOLOGY

FAA Contract No.: DOT-FA78WA-4259 September 1978 to January 1982

Principal Investigators: P.H. Wine and A.R. Ravishankara

Title: Measurement of the Rate of CH_3O_2 + NO_2

Purpose: To measure the rate of CH_3O_2 + NO_2 over the relevant range of tropospheric temperatures and pressures.

Publications:

Ravishankara, A.R., F.L. Eisele, and P.H. Wine, A Kinetic Study of the Reaction of CH_3O_2 with NO_2, FAA-EE-80-38, 1980.

____. "Pulsed Laser Photolysis-Long Path Laser Absorption Kinetics Study of the Reaction of Methylperoxy Radicals with NO_2," Journal of Chemical Physics, Vol. 73, No. 8, October 15, 1980.

____. "Kinetics and Mechanism of the Reaction of OH with HNO_3," presented at the 28th International Union of Pure and Applied Chemistry Congress, Vancouver, British Columbia, August, 1981.

____. "Study of the Reaction of OH with HNO_3: Kinetics and NO_3 Yield," Journal of Physical Chemistry, Vol. 86, No. 10, 1982, pp. 1854-1858

____. "Kinetic Studies of the Reactions of CH_3O_2 with NO_2 and OH with HNO_3," Final Report, March 1983, FAA-EE-83-04.

HARVEY MUDD COLLEGE

FAA Contract No.: DOT-FA78WA-4234 September 1978 to September 1982

Principal Investigator: Gregory L. Kok

Title: Hydrogen Peroxide Measuring Instrumentation

Purpose: To develop instrumentation and demonstrate the capability of measuring hydrogen peroxide in the stratosphere and upper troposphere

Publications:

Kok, Gregory L., "Development of Instrumentation For The Measurement of Hydrogen Peroxide In The Upper Atmosphere," Final Report, September 13, 1982.

INSTITUTE FOR DEFENSE ANALYSES (IDA)

FAA Contract No.: DOT-FA76WA-3757 October 1975 to August 1976

Principal Investigator: Robert C. Oliver

Title: Assessment of Stratospheric Effects and Uncertainties

Purpose: Review the Report of Findings of the DOT/CIAP and other documents concerning stratospheric ozone depletion and to assess effects of high-altitude aircraft on the environment.

Publications:

Oliver, Robert C., "On the Response of Atmospheric Mean Temperature to Stratospheric Dust: An Empirical Apirical Approach," Journal of Applied Meteorology, 15, No. 9, pp. 993-950, 1976.

Hidalgo, Henry, Institute for Defense Analyses (IDA), and Crutzen, Paul J., National Center for Atmospheric Research (NCAR), "The Tropospheric and Stratospheric Composition Perturbed by NO_x Emissions of High-Altitude Aircraft," Journal of Geophysical Research, Vol. 82, No. 37, December 20, 1977, pp. 5833-866.

Oliver, Robert C., with Ernest Bauer, Henry Hidalgo, K.A. Gardner, and Wasyl Wasylkiwskyj, Aircraft Emissions: Potential Effects on Ozone and Climate - A Review and Progress Report, FAA-EQ-77-3, IDA Report No. P-1207, March 1977.

INSTITUTE FOR DEFENSE ANALYSES (IDA)

FAA Contract No.: DOT-FA77WA-3965 April 1977 to August

Principal Investigator: Robert C. Oliver

Title: Analysis of Aircraft Effects

Purpose: To summarize the status of research on the effects of high altitude aircraft operation in the stratosphere. To review the status of modeling efforts and the relationship between ozone amounts, ultraviolet irradiance and skin cancer. To study the atmospheric perturbations caused by atmospheric injection both natural and anthropogenic.

Publications:

Bauer, Ernest, "On the Discrete Aspect of Pollution Jets from Aircraft Takeoffs," Proceedings of Air Quality and Aviation: An International Conference, Reston, VA, October 16-18, 1978, pg. 178; FAA-EE-78-24, November 1978.

____. "Matters Arising: Non-Biogenic Fixed Nitrogen in Antarctic Surface Waters," Nature 276, 96, November 2, 1978.

____. "A Catalog of Perturbing Influences of Stratospheric Ozone, 1955-1975," Journal of Geophysical Research, Vol. 84, No. C11, November 20, 1979, pp. 6929-6940, also published FAA Report No. FAA-EQ-78-20, IDA Paper No. P-1340.

____. "Effect of Past Atmospheric Nuclear Explosions on Total Ozone," Proceedings of the NATO Advanced Study Institute on Atmospheric Ozone: Its Variation and Human Influences, Aldeia das Acoteias, Algarve, Portugal, October 1-13, 1979, FAA-EE-80-20, May 1980, pp. 909-920.

____. A Study of Stratosphere-to-Troposphere Transfer Using Radioactive Tracer Data in a One-Dimensional Parameterization, FAA-EE-80-06, February, 1980, IDA Paper No. p-1456.

Bauer, Ernest, Robert C. Oliver, and Wasyl Wasylkiwskyj, "On the Use of Zr-95 Data from Chinese Atmospheric Thermonuclear Explosion to Study Stratospheric Transport in a One-Dimensional Parameterization," Journal of Geophysical Research, Vol. 83, No. C8, August 20, 1978, pp. 4019-4027.

Broderick, Anthony J., Federal Aviation Administration, and Robert C. Oliver, Institute for Defense Analyses, "The Supersonic Transport," a chapter published in Stratospheric Ozone and Man, Vol. 1, edited by F.A. Bauer and R.B. Ward, CRC Press, Inc., Boca Raton, Florida, 1981.

FAA Contract No. DOT-FA77WA-3965 (cont)

Cutchis, Pythagoras, Modeling Differential Exposure and Differential Sensitivity Characteristics in Non-Melanoma Skin Cancer Incidence, FAA-EE-79-19, September 1979, IDA Paper No. P-1422.

_____. A Formula for Comparing Annual Damaging Ultraviolet (DUV) Radiation Doses at Tropical and Mid-Latitude Sites, FAA-EE-80-21, June 1980, IDA Paper No. P-1492, also presented at NATO Advanced Research Institute, Institute of Physical Oceanography Copenhagen, Denmark, July 28-31, 1980.

_____. On the Linkage of Solar Ultraviolet Radiation to Skin Cancer, FAA-EQ-78-19, September 1978; IDA Paper No. p-1342, also presented at meeting of Association Internationale de Photobiologie and Institute Suisse de Recherches Experimentals sur le Cancer, Lausanne, Switzerland, September 26-29, 1978; meeting of International Fluorocarbon Research Committee of the Manufacturing Chemists Association, March 1, 1981, and meeting of Dermatologists and Pathologists, Washington Hospital Center, Washington, D.C., March 29, 1979.

Hidalgo, Henry, On the Applicability of Two-and One-Dimensional Parameterizations of Atmospheric Tracer Transports to Prognostic Photochemical Models of the Stratosphere, FAA-EE-80-13, March 1980, IDA Paper P-1473.

_____. Status of Representative Two-Dimensional Photochemical Models of the Stratosphere and Troposphere as of Mid-1978, FAA-AEQ-78-23, October 1978, IDA Interim Report No. P-1341.

Oliver, Robert C., "Effects on Atmospheric Ozone of Emissions from Cruise Aircraft: History and Current Status," in Proceedings of the NATO Advanced Study Institute on Atmospheric Ozone: Its Variation and Human Influences, Aldeia das Acoteias, Algarve, Portugal, October 1-13, 1979 pp. 921-963, FAA-EE-80-20, May 1980.

Oliver, Robert C., with Ernest Bauer, and Wasyl Wasylkiwskyj, Recent Developments in the Estimation of Potential Effects of High Altitude Aircraft Emissions on Ozone and Climate, FAA-AEE-78-24, IDA Interim Report No. P-1343, October 1978.

INSTITUTE FOR DEFENSE ANALYSES (IDA)

FAA Contract No.: DTFA01-81-C-10011 January 1981 to January 1982

Principal Investigator: Robert C. Oliver

Title: Analysis of Aircraft Effects

Purpose: To provide an analysis of aircraft effects on the environment.

Publications:

Bauer, Ernest, "Comment on Stratospheric Eddy Diffusion Coefficients from Tracer Data by S.T. Massie & D.M. Hunten, Journal of Geophysical Research, Vol. 86, pg. 9859, 1981," Journal of Geophysical Research Vol. 87, (C7), pg. 5019, June 1982.

____. "Natural and Anthropogenic Sources of Oxides of Nitrogen (NO_x) in the Troposphere," IDA Paper P-1631, January 1982, FAA-EE-82-7, Final Report.

Oliver, Robert, C., "Environmental Aspects of Aircraft Emissions," Fifth International Symposium on Airbreathing Engines, February 16-21, 1981, Bangalore, India.

____. "The SST Controversy: The Situation in 1981," presented at the AAAS Meeting, January 1981, Toronto, Canada.

____. "Cruise Aircraft Effects, 1981 Status," IDA Paper P-1631, Final Report, FAA-EE-82-6, January 1982.

Kowalczyk, Marta, Ernest Bauer, "Lightning as a Source of NO_x in the Troposphere," IDA Paper P-1590, Final Report, FAA-EE-82-4, December 1981.

MAX-PLANCK-INSTITUT FUR CHEMIE

FAA Contract No.: DOT-FA78WA-4264 September 1978 to November 1980

Principal Investigator: Peter Warneck

Title: Measurement of the Photolytic Parameters for Formaldelyde

Purpose: To measure the absorption cross section and quantum yields for HO_2CO as a function of temperature and pressure.

Publications:

Moortgat, Geert K., W. Klippel, K. H. Mobus, Wolfgang Seiler, and Peter Warneck, Laboratory Measurements of Photolytic Parameters for Formaldehyde, FAA-EE-80-47, November 1980.

Moortgat, Geert K., Wolfgang Seiler and Peter Warneck, Photolysis of CH_2O in Air in the Range 250-360 nm at 220 and 300 K, presented at the 10th International Conference on Photochemistry, Iraklion, Crete, Greece, September 6 - 12, 1981.

Moortgat, Geert K., Wolfgang Seiler and Peter Warneck, "Photodissociation of HCHO in air: CO and H_2 quantum yields at 220 and 300 K," Journal of Chemical Physics, Vol. 78, pp 1185-1190, 1983.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)
GODDARD SPACE FLIGHT CENTER (GSFC)

Interagency Agreement No.: DTFA01-80-Y-10559, between U.S. Department of Transportation/Federal Aviation Administration and National Aeronautics and Space Administration/Goddard Space Flight Center

May 1980 to July 1981

Principal Investigator: John E. Allen, Jr.

Title: Assess the environmental effects of cruise altitude emissions of nitric oxide (NO)

Purpose: To obtain a laboratorv measurement of the rate of reaction of NO with O_3.

Publications:

Michael, J.V., J. E. Allen, Jr., and W. D. Brobst, "Temperature Dependence of of the NO + O_3 Reaction Rate from 195 to 369K," Final Report, Journal of Physical Chemistry, 1981, 85, 4109; also presented at the American Geophysical Union Spring Meeting, May 26, 1981 in Baltimore, Maryland.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)
GODDARD SPACE FLIGHT CENTER (GSFC)

FAA Interagency Agreement No.:	DTFA01-80-Y-10554, between U.S. Department of Transportation, Federal Aviation Administration, and National Aeronautics and Space Administration/Goddard Space Flight Center.
	June 1980 to February 1981
Principal Investigator:	William S. Heaps
Title:	Ozone and Hydroxyl Radical Measurements Using a Balloon-borne Lidar System
Purpose:	To conduct one flight of the GSFC balloon-borne lidar system in the Fall of 1980 from Palestine, Texas, to measure the stratospheric hydroxyl radical and ozone. In so far as possible, this flight shall be accomplished in conjunction with other balloon-borne or ground-based measurement systems for the purpose of data intercomparison and correlative studies.

Publications:

Heaps, William S., T.J. McGee, R.D. Hudson, and L.O. Caudill, "Balloon Borne LIDAR System for the Measurement of Stratospheric Hydroxyl and Ozone," Applied Optics, Vol. 21, pg. 2265, 1982.

Heaps, William S. and T.J. McGee, "Balloon Borne LIDAR Measurements of Stratospheric Hydroxyl Radical," Journal of Geophysical Research, Vol. 88, pg. 5281, 1983.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)
GODDARD SPACE FLIGHT CENTER (GSFC)

FAA Interagency Agreement No.:	DTFA01-81-Y-10546, between Federal Aviation Administration and National Aeronautics and Space Administration/Goddard Space Flight Center
	February 1981 to October 1981
Principal Investigator:	A. J. Krueger
Title:	Interagency Agreement with NASA Goddard Space Flight Center for near real-time TOMS experiment
Purpose:	To study the feasibility of obtaining and transmitting to potential user community, total ozone data measured by NASA satellites on a real-time basis. The demonstration of the feasibility would facilitate affected air carriers in developing a method of compliance with the agency rule on airplane cabin ozone contamination.

Publications:

Krueger, A. J., and Daniel F. Sowa, "Near Real-time TOMS 1981 Cooperative Experiment," NASA Report (in preparation).

Puccinelli, E., "TOMS Near Realtime System Design Document" NASA Technical Memorandum 82170, Goddard Space Flight Center, August 1981.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)
LANGLEY RESEARCH CENTER(LaRC)

Partially funded by:
FAA Interagency Agreement No.: DOT-FA77WAI-722, between Department of Transportation, Federal Aviation Administration and National Aeronautics and Space Administration, Langley Research Center (LaRC)

February 1977 to June 1980

Principal Investigator: Frank Allario

Purpose: Laser Development

Publications:

Miller, Matthew D., "Widley Tunable (PbSn)Te Diode Lasers Using Etched Cavities," in NASA Conference Publication 2138; also presented at Heterodyne System and Technology Conference, Williamsburg, VA, March 25-27, 1980, NASA Conference Publication No. 2138.

____. "Development of MBE Grown Pb-Salt Semiconductor Lasers for the 8.0 to 15.0 Micrometer Spectral Region," Draft Final Report, 1981.

Miller, Matthew D. and Y.V. Pickhardt, "(PbSn)Te Diode Lasers," presented at Conference on Lasers and Electro-Optical Systems, San Diego, CA, February 25-29, 1980.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)
LEWIS RESEARCH CENTER (LeRC)

FAA Interagency Agreement No. DOT-FA78WAI-893 between National Aeronautics and Space Administration, and U.S. Department of Transportation/Federal Aviation Administration

June 1978 to February 1982

Principal Investigator: Porter J. Perkins

Title: Aircraft Ozone Measurements

Purpose: To obtain a detailed understanding of the atmospheric ozone distribution and variation in order to assess the effects of aircraft on the ozone layer.

Publications:

Holdeman, James D., Lewis Research Center, and Gregory D. Nastrom, Control Data Corporation, Analysis of Atmospheric Ozone Levels at Commercial Airplane Cruise Altitudes in Winter and Spring 1976-77, FAA-EE-81-1, NASA Report No. TP-1807, April 1981.

_____. "Ozone Contamination in Aircraft Cabins: Results from GASP Data and Analyses," presented at AIAA 19th Aerospace Sciences Meeting, St. Louis, MO, January 12-15, 1981, NASA Report No. TP-81671.

Holdeman, James D., L.C. Papathakos, G.J. Higgins, and Gregory D. Nastrom, Simultaneous Cabin and Ambient Ozone Measurements on Two Boeing 747 Airplanes, Vol. II - January to October 1978, NASA Technical Memorandum 81733, FAA-EE-83-7, March 1984.

Jasperson, William H., and James D. Holdeman, Tabulations of Ambient Ozone Data Obtained by GASP Airliners; March 1975 to July 1979, NASA Technical Memorandum 83742, FAA-EE-83-12, January 1984.

Nastrom, Gregory D., and James D. Holdeman, Tabulations of Ambient Ozone Data Obtained by GASP Airliners; March 1975 to December 1977, FAA-EE-80-43, NASA Report No. TM-81528, September 1980.

Nastrom, Gregory D., James D. Holdeman, and Porter J. Perkins, "Measurements of Cabin and Ambient Ozone on B747 Airplanes," Journal of Aircraft, Vol. 17, No. 4, April 1980.

Perkins, Porter J., James D. Holdeman, and Gregory D. Nastrom, Simultaneous Cabin and Ambient Ozone Measurements on Two Boeing 747 Airplanes. Vol. I, FAA-EE-79-05, NASA Report No. TM-79166, July 1979.

NATIONAL BUREAU OF STANDARDS (NBS)

FAA Interagency Agreement No.: RA76-13-6400223 between Department of Transportation, Federal Aviation Administration and National Bureau of Standards (NBS) National Measurements Laboratory

January 1976 to May 1978

Principal Investigator: David Garvin

Title: Reaction Rate Data, Tabular Input

Purpose: To review Atmospheric Rate Constant Data; to compile $ClONO_2$ and Combustion Kinetic Data

Publications:

Hampson, Robert F., Jr. and David Garvin, (eds.), Reaction Rate and Photochemical Data for Atmospheric Chemistry-1977, NBS Special Publication 513, May 1978.

____. Nitrogen Oxychlorides: A Bibliography on Data for Physical and Chemical Properties of NO, NO_2 and NO_3, NBS Special Publication 478, August 1977.

____. Chemical Kinetics of the Gas Phase Combustion of Fuels, NBS Special Publication 449, October 1976.

(Jointly sponsored by National Aeronautics and Space Administration (NASA) and NBS, Office of Standard Reference Data and Office of Environmental Measurements.)

Westley, Francis, Chemical Kinetics of the Gas Phase Combustion of Fuels (A Bibliography on the Rates and Mechanisms of Oxidation of Aliphatic C_1 to C_{10} Hydrocarbons and of their Oxygenated Derivations), NBS Special Publication No. 449, October 1976.

(Jointly sponsored by NBS, Office of Standard Reference Data, Department of the Navy, Naval Sea Systems Command and Energy Research and Development Administration (ERDA), Division of Conservation, Research, and Technology.

____. Nitrogen Oxychlorides: A Bibliography of Data for Physical and Chemical Properties of ClNO, $ClNO_2$, and $ClNO_3$, NBS Special Publication No. 478, August 1977.

(Jointly sponsored by NBS, Office of Standard Reference Data and Office of Air and Water Measurements, and National Aeronautics and Space Administration)

NATIONAL BUREAU OF STANDARDS (NBS)

FAA Interagency Agreement No.: DOT-FA79WAI-005 between Federal Aviation Administration and National Bureau of Standards (NBS), Center for Thermodynamics and Molecular Science; jointly sponsored by National Aeronautics and Space Administration (NASA), Upper Atmospheric Research Office and NBS, Office of Standard Reference Data

December 1978 to March 1980

Principal Investigator: Robert F. Hampson

Title: Prepare detailed evaluations of NO_x and $O(^1D)$ reactions.

Purpose: To compile an evaluation of all other atmospheric reactions in individual data sheet form.

Publications:

Baulch, D.L., R.A. Cox, Robert F. Hampson Jr., J.A. Kerr, J. Troe, and Robert T. Watson, "Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry," Journal of Physical and Chemical Reference Data, Vol. 9, No.2, pp. 295-471, 1980.

Hampson, Robert F., Jr., Chemical Kinetic and Photochemical Data Sheets for Atmospheric Reactions, FAA-EE-80-17, NBS IR-80-2032, April 1980.

NATIONAL BUREAU OF STANDARDS (NBS)

FAA Interagency Agreement No.:	DOT-FA01-80-Y-10532 between Department of Transportation, Federal Aviation Administration and National Bureau of Standards (NBS), Office of Standard Reference Data; jointly supported by National Aeronautics and Space Administration (NASA), Upper Atmospheric Physics Section
	April 1980 to June 1981
Principal Investigator:	Robert F. Hampson, Jr.
Title:	Evaluation of Kinetics and Photochemical Data for Atmospheric Modeling
Purpose:	To update and maintain an evaluation of the chemical reaction rates and photochemical parameters required as the data base for atmospheric models used for the assessment of aircraft effects on the environment.

Publications:

Baulch, D.L., R.A. Cox, Robert F. Hampson, Jr., J.A. Kerr, J.Troe, and R.T. Watson, "Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry," report of the CODATA Task Group on Chemical Kinetics, Journal of Physical and Chemical Reference Data, Vol. 9, 1980, pp. 295-471.

NATIONAL BUREAU OF STANDARDS (NBS)

FAA Interagency Agreement No.:	DTFA01-81-Y-10552, between Department of Transportation/Federal Aviation Administration and National Bureau of Standards
	May 1981 to November 1982
Principal Investigator:	Robert F. Hampson, Jr.
Title:	Evaluation of Kinetics and Photochemical Data for Atmospheric Modeling
Purpose:	To update and maintain an evaluation of the chemical reaction rates and photochemical parameters required as the data base for atmospheric models used for the assessment of aircraft effects on the environment.

Publications:

Baulch, D.L., R.A. Cox, P.J. Crutzen, R.F. Hampson Jr., J.A. Kerr, J. Troe, and R.T. Watson, "Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry: Supplement I CODATA Task Group on Chemical Kinetics," Journal of Physical and Chemical Reference Data, Vol. 11, No. 2, pp. 327-496, 1982.

NATIONAL BUREAU OF STANDARDS (NBS)

FAA Interagency Agreement No.:	DOT-FA79WAI-112, between Department of Transportation, Federal Aviation Adminstration and National Bureau of Standards
	November 1979 to June 1981
Principal Investigator:	Michael J. Kurylo
Title:	Reduction of uncertainties in the predicted environmental effects of cruise-altitude aircraft emissions
Purpose:	Laboratory experimental program to provide for the measurement of chemical reaction rates and photo-chemical data to support the High Altitude Pollution Program at the Office of Environment and Energy. This effort will help reduce the uncertainties in the predicted environmental effects of cruise-altitude aircraft emissions.

Publications:

Kurylo, Michael, J., Odo Klais, and Allan H. Laufer, "A Mechanistic Investigation of the HO + HO_2 Reaction," Final Report (Draft copy - Approved June, 1981), Journal of Physical Chemistry Vol. 85, pp. 3674-3678, 1981.

NATIONAL BUREAU OF STANDARDS (NBS)

FAA Interagency Agreement No.:	DOT-FA79WA1-026 between Department of Transportation, Federal Aviation Administration and National Bureau of Standards (NBS), Chemical Kinetics Division April 1979 to July 1980
Principal Investigator:	Wing Tsang
Title:	Theoretical Treatment of Pressure Dependent Reactions
Purpose:	To apply unimolecular reaction rate theory to possible complex intermediates formed in radical-radical bi-molecular reactions.

Publications:

Tsang, Wing, Disproportionation Reactions of Small Inorganic Radicals in the Context of Intermediate Complex Formation, FAA-EE-80-45, October 1980.

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH (NCAR)

FAA Interagency Agreement No.: DOT-FATQWAI-684 between Departrment of Transportation/Federal Aviation Administration and National Center for Atmospheric Research (NCAR)

October 1976 to October 1982

Principal Investigator: L.E. Heidt

Title: Measurements at 45 Kilometers Using Cryogenic Sampling and Other Techniques

Purpose: To conduct four (2 at the equator and 2 at northern latitudes) atmospheric balloon and aircraft cryogenic sampling missions and provide data analysis.

Publications:

Ehhalt, Dieter H., H.W. Patz, W. Pollock, L.E. Heidt, and R. Lueb, "Measurement of Atmospheric Water Vapor by Cryogenic Collection," in Atmospheric Water Vapor, edited by Adarsh Deepak, Thomas Wilkerson, and Lothar Ruhnke, Academic Press, New York, 1980, pp. 303-314; also presented at Workshop on Atmospheric Water Vapor, Vail, Colorado, September 11-13, 1979.

Pollock, Walt, Leroy E. Heidt, R. Lueb, and Dieter H. Ehhalt, "Measurement of Stratospheric Water Vapor by Cryogenic Collection," Journal of Geophysical Research, Vol. 85, No. C10, October 20, 1980, pp. 5555-5568.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

FAA Interagency Agreement No.: DOT-FATQWAI-733 between National Oceanic and Atmospheric Administration and Department of Transportation, Federal Aviation Administration

June 1977 to September 1980

Principal Investigator: Dieter Kley

Title: Laboratory Chemistry Studies

Purpose: To determine in situ J values for O_3, O_2, N_2O, and NO and measure the altitude profiles of H_2O and H_2O_2.

Publications:

Ellsaesser, Hugh W. (U.S. DOE), John E. Harries, Dieter Kley (NOAA), and Rudolf Penndorf, "Stratospheric H_2O," Planetary and Space Science, Vol. 28, 1980, pp. 827-845, also LLNL Report Nos. UCRL-82512 and 82542.

Kley, Dieter, "Measurement of H_2O Vapor in the Stratosphere," presented at AGU/AMS Fall Annual Meeting, San Francisco, CA, December 4-8, 1978.

Kley, Dieter, and Edward J. Stone, "Measurement of Water Vapor in the Stratosphere by Photodissociation with Ly α (1216 A) light," Rev. Sci. Instrument., Vol. 49, pp 691-696, 1978.

Kley, Dieter, John W. Drummond, M. McFarland, and S.C. Liu, "Tropospheric Profiles of NO_x," Journal of Geophysical Research, Vol. 86, No. C4, April 20, 1981, pp. 3153-3161.

Kley, Dieter, John W. Drummond, and Arthur L. Schmeltekopf, "On the Structure and Microstructure of Stratospheric Water Vapor," Atmospheric Water Vapor, edited by Adarsh Deepak, Thomas Wilkerson, and Lothar Ruhnke, Academic Press, New York, 1980, pp. 315-327.

Kley, Dieter, Edward J. Stone, "Measurement of Water Vapor in the Stratosphere by Photodissociation with Ly a (1216 A) Light," Review of Scientific Instruments, Vol. 49, No. 6, June 1978.

Kley, Dieter, Edward J. Stone, W.R. Henderson, John W. Drummond, W.J. Harrop, Arthur L. Schmeltekopf, T.L. Thompson, and R.H. Winkler, "In-situ Measurements of the Mixing Ratio of Water Vapor in the Stratosphere," Journal of the Atmospheric Sciences, Vol. 36, No. 12, December 12, 1979.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

FAA Interagency Agreement No.: DOT-FATQWAI-733 (cont)

Publications: (cont)

Liu, S.C., Dieter J. Kley, M. McFarland, Jerry D. Mahlman and Hiram Levy II, "On the Origin of Trophospheric Ozone," Journal of Geophysical Research, Vol. 85, No. C12, Decemher 20, 1980, pp. 7546-7552.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

FAA Interagency Agreement No.:	DTFA01-80-Y-10568 between Department of Transportation, Federal Aviation Administration and National Oceanic and Atmospheric Administration
	July 1980
Principal Investigator:	Dieter Kley
Title:	Measurements of Atmospheric H_2O, NO_2, CO, H_2O_2 by Dissociative Fluorescence and Resonance Fluorescence
Purpose:	To improve the H_2O vapor instrument and to explore the use of resonance fluorescence to detect other atmospheric molecules.

Publications:

Kley, Dieter, " Ly(α) Absorption Cross Section of H_2O and O_2," Journal of Atmos. Chem., (submitted, 1984).

Volz, Andreas, and Dieter Kley, " A Resonance-Fluorescence Instrument for in-Situ Measurement of Atmospheric Carbon Monoxide," (in preparation).

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

FAA Interagency Agreement No.: DOT-FA78WAI-850 between Department of Transportation, Federal Aviation Administratin and National Oceanic and Atmospheric Administration

January 1978 to December 1982

Principal Investigator: W. D. Komhyr

Title: Analysis and Intercomparison of Ozone Measurements from Dobson Instruments

Purpose: To provide for improved global total ozone measurements obtained over the past 15 years by Dobson spectrophotometers which is necessary for the understanding of atmospheric ozone distribution and variations, including long-term trends.

Publications:

Komhyr, W. D., participated and contributed to the Harper Ferry Workshop documented in "The Stratosphere: Present and Future", December 1979, NASA Reference Publication 1049.

Komhyr, W.D., "Dobson Spectrophometer Systematic Total Ozone Measurement Error," NOAA Air Resources Laboratories, Boulder, CO, Published, Geophysical Reserch Letters, Approximately February/March 1980.

Komhyr, W. D., and R. D. Evans, "Dobson Spectrophotometer Total Ozone Measurement Errors caused by Interfering Absorbing Species Such as SO_2, NO_2 and Photochemically Produced O_3 IN Polluted Air," NOAA Air Resources Laboratories, Boulder CO, Published, Geophysical Research Letters, approximately February/March 1980.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

FAA Interagency Agreement No.: DTFA01-80-Y-10565 between U.S. Department of Commerce/National Oceanic and Atmospheric Administration and Department of Transportation/Federal Aviation Administration

June 1980

Principal Investigator: M. McFarland

Title: NO, NO_2, and Total Odd-Nitrogen Stratospheric Balloon Flights

Purpose: To develop an improved version of the chemiluminescent/photolytic method for measuring NO and NO_2 and to apply the technique to stratospheric measurements

Publications:

Two manscripts are being prepared to describe the results of four stratospheric balloon flights in which NO, NO_2, and O_3 were measured simultaneously.

NAVAL RESEARCH LABORATORY

FAA Interagency Agreement No.:	DTFA01-81-Y-10512, between Naval Research Laboratory, and Department of Transportation, Federal Aviation Administration
	January 1982 to August 1982
Principal Investigator:	Don Anderson
Title:	Effects of Sphericity on the Multiple Scattering of Solar Radiation in the Troposphere and Stratosphere.
Purpose:	To use the previously developed spherical code techniques to develop an isotopic spherical code for the troposphere and stratosphere as a function of altitude and solar zenith angle. The results of this development shall be directly compared with plane and parallel models.

Publications:

Anderson, Jr., Donald E., "The Solar Radiation Field at Twilight Below 100 KM: A Spherical Model," Final Report, May 1982, FAA-EE-82-18.

Anderson, Jr., Donald E., "The Troposphere-Stratosphere Radiation Field at Twilight: A Spherical Model," Planetary and Space Science, Vol.11, pg. 1517, 1983.

NAVAL RESEARCH LABORATORY

FAA Interagency Agreement No.: DOT-FA77WAI-748 between Department of Transportation, Federal Aviation Administration and Naval Research Laboratory

June 1977

Principal Investigator: H. J. Mastenbrook

Title: Measurement of Stratospheric H_2O

Purpose: To design, develop and test a frostpoint hygrometer-type instrument to measure atmospheric water vapor. To continue periodic water vapor measurement presently conducted by NRL and compare data obtained for a period of one year with soundings in the vicinity of Boulder, Colorado.

Publications:

Mastenbrook, H.J., "Operation Manual for Model 1012 Hygrometer," Report No. NRL Instruction Book 176, December 1981.

Mastenbrook, H. J. and R. E. Daniels, "Measurements of Stratospheric Water Vapor Using a Frost-Point Hygrometer," in Atmospheric Water Vapor, edited by Adarsh Deepak, Thomas Wilkerson, and Lothar Ruhnke, Academic Press, New York, 1980, pp. 329-342; also presented at the International Workshop on Atmospheric Water Vapor held in Vail, CO, September 11-13, 1979.

NAVAL RESEARCH LABORATORY

FAA Interagency Agreement No.: DOT-FA76WAI-684 between Department of Transportation/Federal Aviation Administration and Naval Research Laboratory

June 1976 to October 1976

Principal Investigator: Commander W. Smith

Title: Balloon Launch, Tracking, and Recovery Costs for NO Detector Flight to 45 km

Purpose: To provide flight services in connection with a balloon launch conducted by the University of Wyoming to detect nitric oxide up to an altitude of 45 km.

Publications:

Drummond, John W., James M. Rosen, and David J. Hofmann, "Measurement of Nitric Oxide to 45 km," Nature, Vol. 265, 1977, p. 319.

NORTH ATLANTIC TREATY ORGANIZATION (NATO)

Memorandum of Understanding: AIA/CA-18 between U.S. Department of Transportation, Federal Aviation Administration, and North Atlantic Treaty Organization (NATO)

March 1979 to May 1980

Principal Investigators: M. DiLullo and Marcel Nicolet

Title: Advanced Study Institute, "Atmospheric Ozone: Its Variations and Human Influences"

Purpose: To promote a workshop resulting in an assessment of the state-of-the-art understanding of atmospheric ozone from an international viewpoint.

Publications:

Nicolet, Marcel, Director, and Arthur C. Aikin, Editor, Proceedings of the NATO Advanced Study Institute on Atmospheric Ozone: Its Variation and Human Influences, Aldeia das Acoteias, Algarve, Portugal, October 1-13, 1979, FAA-EE-80-20, May 1980.

OREGON GRADUATE CENTER FOR STUDY AND RESEARCH

FAA Contract No.: WI-78-3745-1 April 1978 to October 1978

Principal Investigator: R.A. Rasmussen

Title: Trace Gas Analysis of Concorde Air Samples

Purpose: To participate in analysis of Concorde air samples and compare with data obtained on same species during previous high altitude flights. Also to evaluate the sampling program and describe needs to obtain the maximum scientific knowledge from the program.

Publications:

Rasmussen, R.A., Corcorde Air Sampling Program, Intercalibrations and Collaborative Measurements, FAA-EE-78-25, September 26, 1978.

Rasmussen, R.A., S.A. Penkett, N.J.D. Prosser, "Measurement of Carbon Tetrafluoride in the Atmosphere," Nature, Vol. 277, February 15, 1979.

OREGON GRADUATE CENTER FOR STUDY AND RESEARCH

FAA Contract No.: DOT-FA79WA-4285 February 1979 to November 1981

Principal Investigator: R.A. Rasmussen

Title: Concorde Whole Air Sampling

Purpose: To conduct whole air sampling on not less than 10 Concorde flights between Dulles and Heathrow. Perform trace gas analysis on these samples and compare with data previously obtained.

Publications:

Penkett, S.A., N.J.D. Prosser, R.A. Rasmussen, and M.A.K. Khalil, "Atmospheric Measurements of CF_4 and Other Fluorocarbons Containing the CF_3 Grouping," Journal of Geophysical Research, Vol. 86. 1981, pp. 5172-5178.

Rasmussen, R.A., and M.A.K. Khalil, "Atmospheric Halocarbons: Measurements and Analysis of Selected Trace Gases," Proceedings of the NATO Advanced Study Institute on Atmospheric Ozone: Its Variation and Human Influences, Aldeia das Acoteias, Algarve, Portugal, October 1-13, 1979, FAA-EE-80-20, May 1980.

Rasmussen, R.A., M.A.K. Khalil, S.A. Penkett, and N.J.D. Prosser, "$CHClF_2$(F22) in the Earth's Atmosphere," Geophysical Research Letters, Vol. 7, October 1980.

OREGON STATE UNIVERSITY

FAA Contract No.:	DOT-FA77WA-3992	August 1977 to August 1980
Principal Investigator:	Edwin F. Danielsen	
Title:	Stratospheric to Tropospheric Exchange Processes	
Purpose:	To develop, test and document an objective methodology based on routinely available meterological data for the quantitative determination of stratosphric-tropospheric mass exchange. To use this methodology to determine all relevant transport parameters for use in two-dimensional models of the stratosphere.	

Publications:

Danielsen, Edwin F., An Objective Method for Determining the Generalized Transport Tensor for Two-Dimensional Eulerian Models, FAA-EE-80-32, August 1980.

ORI, INC.

FAA Contract No.: DTFA01-C-82-10030 and DTFA01-C-83-10072

February 1982 to August 1984

Principal Investigator: James S. Bauchspies

Title: Technical Information Support and Documentation for the Low and High Altitude Emissions Programs.

Purpose: To provide technical information support and documentation for the Low and High Altitude Emissions Programs.

Publications:

Ormond, Florence M., and Rebecca S. Kibling, HAPP Reports: Bibliography of Work Supported by Federal Aviation Administration's High Altitude Pollution Program, May 1983, updated 1984.

Ormond, Florence M., editor, Upper Atmospheric Programs Bulletin, bi-monthly publication jointly funded by National Aeronautics and Space Administration, published since January 1976.

The Bulletin is a cooperative enterprise under Memorandum of Understanding W.O. 489 between National Aeronautics and Space Administration and Federal Aviation Administration concerning interagency cooperation on stratospheric studies. August 1976, ongoing.

ORI, INC.

FAA Contract No. DOT-FA76WA-3750 October 1975 to September 1976

Principal Investigator: C. W. Patten

Title: High Altitude Pollution Program Support

Purpose: To provide technical support, documentation and program evaluation services to the High Altitude Pollution Program.

Publications:

Greenstone, Reynold, "Modeling Man's Influence on Stratospheric Ozone." Environmental Science and Technology, Vol. 12, No. 3, March 1978, pp. 270-74.

____. "The Possibility that Changes in Cloudiness will Compensate for Changes in Ozone and Lead to Natural Protection against Ultraviolet Radiation," Journal of Applied Meteorology, Vol. 17, No. 1, January 1978, pp. 107-109.

____. Technical Information and Documentation Support of the High Altitude Pollution Program, FAA-EQ-77-1, ORI Report No. 1099, October 29, 1976.

Sundararaman, Narasimhan, Initial Summary of Upper Atmospheric Data, FAA-EQ-76-4, April 1976.

____. Summary of Upper Atmospheric Data, FAA-EQ-77-2, ORI Report No. TR-1112, October 1976.

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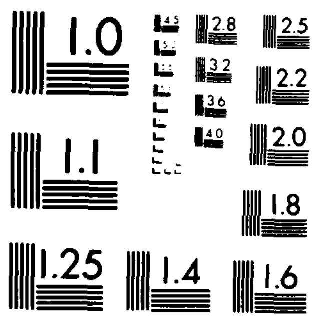
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ORI, INC.

FAA Contract No.: DOT-FA78WA-4219 September 1978 to January 1982

Principal Investigator: C.W. Patten

Title: High Altitude Pollution Program Support

Purpose: To provide specific documentation and dissemination of technical information in support of the High Altitude Pollution Program.

Publications:

Baranano, Maria T., editor, HAPP Reports: Bibliography of Work Supported by Federal Aviation Administration's High Altitude Pollution Program, December 1981.

Ormond, Florence M., Upper Atmospheric Programs Bulletin, bi-monthly publication jointly funded by National Aeronautics and Space Administration, published since January 1976.

The Bulletin is a cooperative enterprise under Memorandum of Understanding W.O. 489 between National Aeronautics and Space Administration and Federal Aviation Administration concerning interagency cooperation on stratospheric studies. August 1976, ongoing.

DR. RUDOLPH PENNDORF

FAA Contract No.: WI-76-1085-1 November 1975 to May 1976

Principal Investigator: Rudolph Penndorf

Title: Analysis of Measurement Requirements

Purpose: To analyze data obtained under DOT/CIAP and recommend specific requirements for future stratospheric measurements under HAPP.

Publications:

Penndorf, Rudolph, Analysis of Measurement Requirements, Final Report, May 14, 1976.

DR. RUDOLPH PENNDORF

FAA Contract No.:	WI-78-3740-1	April 1978 to December 1978
Principal Investigator:	Rudolph Penndorf	
Title:	Analysis of Ozone and Water Vapor Field Measurement Data	
Purpose:	To review and update results obtained for ozone and water vapor data under contract DOT-FATQWA-3866.	

Publications:

Penndorf, Rudolph, Analysis of Ozone and Water Vapor Field Measurement Data, April-November 1978, FAA-EE-78-29, .

PENNSYLVANIA STATE UNIVERSITY

FAA Contract No.: DOT-FA79WA-4393 September 1979 to June 1981

Principal Investigator: Julian Heicklen

Title: Direct Determination of the Reaction of CH_3O_2 with NO

Purpose: *To measure the rate and temperature dependence of the reaction of methyl peroxy radicals with nitric oxide.*

Publications:

Simonaitis, R. and Julian Heicklen, The Reaction of CH_3O_2 with NO, FAA-EE-81-5, March 1981.

Simonaitis, R., and Julian Heicklen, "Rate Coefficient for the Reaction of CH_3O_2 with NO from 218 to 365°K." Journal of Physical Chemistry, Vol. 85, pg. 2946, 1981.

ROCKWELL INTERNATIONAL SCIENCE CENTER

FAA Contract No.: DOT-TSC-1202 June 1976 to June 1977

Principal Investigator: Alan B. Harker

Title: Heterogeneous Decomposition of Ozone on Sulfuric Acid at Stratospheric Temperatures

Purpose: To develop apparatus for generating aerosol mist and to measure the rate of ozone decomposition over the mist.

Publications:

Harker, Alan B., Heterogenous Decomposition of Ozone on Sulfuric Acid Surfaces at Stratospheric Temperatures, FAA-AEQ-77-12, RI Report No. SC5078.18FR, September 1977.

Harker, Alan B., and W.W. Ho, "Heterogeneous Ozone on Sulfuric Acid Surfaces at Stratospheric Temperatures," Atmospheric Environment, Vol. 13, 1979, pp. 1005-1010.

ROCKWELL INTERNATIONAL SCIENCE CENTER

FAA Contract No.:	DOT-FA79WA-4378	September 1979 to February 1981
Principal Investigator:	Alan B. Harker	
Title:	Kinetics of the Heterogeneous Hydrolysis of Dinitrogen Pentoxide	
Purpose:	To determine the rate of formation of nitric acid dinitrogen pentoxide and water vapor in the presence of simulated stratospheric aerosol surfaces.	

Publications:

Harker, Alan B. and D.R. Strauss, Kinetics of the Heterogenous Hydralysis of Dinitrogen Pentoxide (N_2O_5) Over the Temperature Range 214-263K, FAA-EE-81-3, February 1981.

SCIENCE APPLICATIONS, INC.

FAA Contract No.: DOT-FA79WA-4306 July 1979 to November 1981

Principal Investigator: Robert J. Gelinas

Title: Assess the Nature of Local Variability of Trace Species of Stratospheric Importance

Purpose: To study the local variability of trace species concentrations so that their atmospheric measurements may be used to (a) verify one- and two-dimensional stratospheric models, (b) develop an improved stratospheric measurement strategy, and (c) estimate the probable range of inaccuracies inherent in present stratospheric ozone models

Publications:

Gelinas, Robert J., "The Nature of Local Variability of Trace Species of Stratospheric Importance," presented at the High Altitude Pollution Program Workshop, Office of Environment and Energy, FAA, December 3, 1980.

Gelinas, Robert J., and J. Peter Vajk, "Diurnal Analysis of Local Variabilities in Atmospheric NO_3," Journal of Geophysical Research, Vol. 86, No. C8, pp. 7369-7377, August 20, 1981.

Gelinas, Robert J., and J. Peter Vajk, "Local Variability of Trace Species in the Stratosphere," Final Report presented to FAA High Altitude Physics Program, July 1982.

SMITHSONIAN INSTITUTION

FAA Contract No.: DOT-FA79WA-4362 September 1979 to December 1981

Principal Investigator: Harrison E. Radford

Title: Direct Determination of the Rate of Reaction of Methoxy Radicals (CH_3O) with Molecular Oxygen (O_2) and Ozone (O_3).

Purpose: To measure by direct observation of reactants and/or products over the relevant range of tropospheric pressure and temperature the absolute rate coefficients and products for the reaction of methoxy radicals (CH_3O) with molecular Oxygen (O_2) and Ozone (O_3).

Publications:

Fortuno, Guadalupe, "Reactions of Methoxy and Hydroxymethyl Radicals with Oxygen, Nitrogen Dioxide, and Ozone," PhD Thesis, Department of Physics, Harvard University, May 1982.

Radford, Harrison, E., "Reactions of Methoxy Radicals with Atmospheric Gases," (Draft) of Final Report September 1981.

SRI INTERNATIONAL

FAA Contract No.: DOT-FA78WA-4228 September 1978 to June 1981

Principal Investigator: John R. Barker

Title: Measurement of Reaction Rates for Pernitric Acid with OH and $O(^3P)$

Purpose: To determine the rate of reaction of OH and $O(^3P)$ with HO_2NO_2 as a function of temperature.

Publications:

Barker, John, R., Paula L. Trevor, Richard A. Kenley, Jeng-Sian Chang, John E. Davenport, Bosco Y. Lan, and Graham Black, "Stratospheric Reactions of Peroxynitric Acid," Final Report, April 1981.

Chang, Jeng-Sian, Paula L. Trevor, and John R. Barker, "$O(^3P)$ + $HOONO_2$ Products: Temperature-Dependent Rate Constants," International Journal of Chemical Kinetics, 1981.

Kenley, Richard, Paula L. Trevor and Bosco Y. Lan, "Preparation and Thermodecomposition of Pernitric Acid ($HOONO_2$) in Aqueous Media," Journal of American Chemical Society, Vol. 103, pg. 2203, 1981.

Trevor, Paula L., Jeng-Sian Chang, and John R. Barker, "Kinetics of Some Bimolecular Reactions of Pernitric Acid (HO_2 NO_2)," 14th Informal Conference on Photochemistry, Newport Beach, California, March 30-April 3, 1980.

Trevor, Paula L. and John R. Barker, "H + $HOONO_2$ Products: Temperature-Dependent Rate Constant," International Journal of Chemical Kinetics, Vol. 13, pg. 1163, 1982.

Trevor, Paula L., Graham Black and John R. Barker, "The Reaction Rate Constant for OH + $HOONO_2$ Products Over the Temperature Range 246K to 324K," Journal of Physical Chemistry, Vol. 86, pg. 1661, 1982.

SRI, INTERNATIONAL

FAA Contract No.: DOT-TSC-1204 June 1976 to June 1977

Principal Investigator: John E. Davenport

Title: NO_2 Photolysis

Purpose: To measure the NO_2 photolysis cross-sections and quantum yields between wavelengths 385 to 425 nm and temperatures 200-300 K.

Publications:

Davenport, John E., Determination of NO_2 Photolysis Parameters for Stratospheric Modeling, FAA-AEQ-78-05, June 1978.

SRI INTERNATIONAL

FAA Contract No.: DOT-FA78WA-4263 September 1978 to May 1980

Principal Investigator: John E. Davenport

Title: Measurement of the Photolytic Parameters for O_3

Purpose: To determine the cross-section and quantum yields for O_3 photolysis over the threshold region.

Publications:

Davenport, John E., Parameters for Ozone Photolysis as a Function of Temperature at 280-370 nm, FAA-EE-80-44R, April 1980.

U.S. DEPARTMENT OF ENERGY, BROOKHAVEN NATIONAL LABORATORY (BNL)

FAA Interagency Agreement No.: DOT-FA78WAI-859 between Department of Transportation, Federal Aviation Administration, and U.S. Department of Energy

May 1978

Principal Investigator: Stephen E. Schwartz

Title: Investigation of Tropospheric Rainout Process

Purpose: To review available literature addressing the chemistry of the interaction of nitrogen oxides and oxyacids with atmospheric water. As a result of the review, to perform necessary modeling, laboratory measurements, and field measurements to define the tropospheric rainout removal process.

Publications:

Lee, Y.N., and S.E. Schwartz, "Kinetics of Reactive Dissolution of NO_2 in Water at Low Partial Pressure," presented at 180th Fall Meeting of American Chemical Society, San Francisco, CA, August 25-29, 1980, BNL Report No. 27830.

Lee, Y.N., and S.E. Schwartz, "Reaction Kinetics of Nitrogen Dioxide with Liquid Water at Low Partial Pressure," Journal of Phys. Chem. Vol. 85, pp. 840-848, 1981, BNL Report No. 28532.

Lee, Y.N., and S.E. Schwartz, "Evaluation of the Rate of Uptake of Nitrogen Dioxide by Atmospheric and Surface Liquid Water," J. Geophys. Res., Vol. 86, pp. 11971-11983, 1981.

Lee, Y.N., and S.E. Schwartz, "Heterogeneous Removal of Atmospheric NO_x by Reactions in Liquid Water," International Union of Pure and Applied Chemistry, 28th Congress, August 16-21, 1981, Paper SE-40, BNL Report No. 29705.

Levine, S.Z., and S.E. Schwartz, "Parameterization of Complex Chemical Systems," MAP3S/RAINE Biannual Review Meeting, Jekyll Island, Georgia, November 16-19, 1981, BNL Report No. 30585.

Levine, S.Z., and S.E. Schwartz, "In-Cloud and Below-Cloud Scavenging of Nitric Acid Vapor," BNL Report No. 28683, 1980, Atmospheric Environment, Vol. 16, pp. 1725-1734, 1982.

Markovits, G.Y., S.E. Schwartz, and L. Newman, "Hydrolysis Equilibrium of Dinitrogen Trioxide in Dilute Acid Solution," Inorganic Chemistry, Vol. 20, pp. 445-450, 1981, BNL Report No. 28218.

U.S. DEPARTMENT OF ENERGY, BROOKHAVEN NATIONAL LABORATORY (BNL)

FAA Interagency Agreement No.: DOT-FA78WAI-859 (cont)

Publications: (cont)

Schwartz, S.E., "Equilibria in the Nitrogen Oxide-Nitrogen Oxyacid-Water System," BNL Report No. 27827R, 1980, American Chemical Society 180th National Meeting, August 25-29, 1980, Division of Physical Chemistry, Paper PHYS-221.

Schwartz, S.E., "Aqueous Phase NO_x Processes in the Atmosphere," in Formation and Fate of Atmospheric Nitrates, Workshop Proceedings. EPA-ESRL, Research Triangle Park, N.C., October 1979, EPA-ORD Report EPA-600/9-81-025, pp. 179-195, June, 1981.

Schwartz, S.E., "Aqueous-Phase Reactions in Atmospheric Sulfate and Nitrate Formation," American Chemical Society 182nd National Meeting, August 24-28, 1981, Division of Physical Chemistry, Paper PHYS-148, BNL Report No. 29704.

Schwartz, S.E., "Gas-Aqueous Reactions of Sulfur and Nitrogen Oxides in Liquid-Water Clouds," in SO_2, NO, and NO_2 Oxidation Mechanisms: Atmospheric Considerations, J.G. Calvert, Ed., Butterworth, Boston, pp 173-208, 1984, *in press*, BNL Report No. 31211, American Chemical Society 183rd National Meeting, March-April, 1982, Division of Environmental Chemistry, Paper ENVI-51.

Schwartz, S.E., and Warren H. White, "Solubility Equilibria of the Nitrogen Oxides and Oxyacids in Dilute Aqueous Solution," Advances Environmental Science and Engineering, Vol. 4, pp. 1-115, 1981.

Schwartz, S.E., and Warren H. White, "Kinetics of the Reactive Dissolution of the Nitrogen Oxides and Oxyacids in Aqueous Solution," BNL Report No. 30178, November 1981, Advan. Environ. Sci. Tech. Vol. 12, John Wiley and Sons, pp. 1-116, 1983.

U.S. DEPARTMENT OF ENERGY,
LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

FAA Interagency Agreement No.: DOT-TSC-(RA)-76-1 between Department of Transportation, Federal Aviation Administration and U.S. Department of Energy

August 1975 to June 1976

Principal Investigator: Fred Luther

Title: Numerical Simulation of Atmospheric Response

Purpose: To refine the LLNL one-dimensional model for the stratosphere in the areas of photochemical kinetics and radiation transfer

Publications:

Chang, Julius S., and Donald J. Wuebbles, "A Study of the Atmospheric Budget for Odd Nitrogen," presented at the American Geophysical Union Fall Meeting, San Francisco, CA, December 8-12, 1975, LLNL Report No. UCRL-77299.

Chang, Julius S., Donald J. Wuebbles, and William H. Duewer, "Sensitivity to Parameter Uncertainties for Ozone Reduction from Chlorofluoromethanes," presented at the 12th International Symposium on Free Radicals, Laguna Beach, CA, January 4-9, 1976, LLNL Report No. UCRL-77432 (Preprint).

Duewer, W. H., H. W. Ellsaesser, D. J. Wuebbles, and J. S. Chang, "NO Catalytic Ozone Destruction: Sensitivity to Rate Coefficients," presented at meeting of American Chemical Society, Division of Environmental Chemistry, San Francisco, CA, August 1976, LLNL Report No. UCRL-78038.

Duewer, William H., Donald J. Wuebbles, Hugh W. Ellsaesser and Juluis S. Chang "NO_x Catalytic Ozone Destruction: Sensitivity to Uncertainties in Rate Coefficients," presented at Symposium on Atmospheric Ozone, International Commission of Atmospheric Ozone/Atmospheric Chemical and Global Pollution of the International Association of Meteorology and Atmospheric Physics, Dresden, Germany, August 9-17, 1976, LLNL Report No. UCRL-78037 (Preprint).

____. "Ozone Drop and Depletion Theories," Science News, Vol. 109, No. 1, 1976, LLNL Report No. UCRL-77833 (Preprint).

____. "The Role of Deserts on Global Climates," presented at American Geophysical Union Fall Meeting, San Francisco, CA, December 8-12, 1975, LLNL Report No. UCRL-77309 (Abstract)

Ellsaesser, Hugh W., Michael C. MacCracken, Gerald L. Potter, and Frederick M. Luther, "An Additional Model Test of Positive Feedback from High Desert Albedo," Quarterly Journal of the Royal Meteorological Society, Vol. 102, 1976, pp. 543-554, LLNL Report No. UCRL-77121 (Preprint).

U.S. DEPARTMENT OF ENERGY,
LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

FAA Interagency Agreement No. DOT-TSC-(RA)-76-1 (cont)

Publications: (cont)

Luther, Frederick M., "Aerosols and the Radiation Budget: One-Wavelength Versus Full-Flux Calculations," Proceedings of the Symposium on Radiation in the Atmosphere, Radiation Commission and Commission on Atmospheric Chemistry and Global Pollution, Garmisch-Partenkirchen, Germany, August 19-28, 1976, H-J Bolle (ed.), Science Press, Princeton, NJ, 1977, LLNL Report No. UCRL-77870 (Abstract).

____. Lawrence Livermore Laboratory First Annual Report to the High Altitude Pollution Program, FAA-EQ-77-6, LLNL Report No. UCRL-50042-76, June 1976.

____. "One Wavelength Solar Radiation Calculations: Rayleigh Scattering and Gaseous Absorption," presented at the 2nd Conference on Atmospheric Radiation, Arlington, VA, October 29-31, 1976, LLNL Report No. UCRL-76680 (Preprint).

____. "A Parameterization of Solar Absorption by Nitrogen Dioxide," Journal of Applied Meteorology, Vol. 15, 1976, pp. 479-481.

Luther, Frederick M., Julius S. Chang, and Donald J. Wuebbles, "Radiation Feedback Effects in a One-Dimensional Stratospheric Model," presented at Fall Annual Meeting of American Geophysical Union, San Francisco, CA, December 8-12, 1975, LLNL Report No. UCRL-77298 (preprint).

Luther, Frederick M., and Robert J. Gelinas, "Effects of Molecular Multiple Scattering and Surface Albedo on Atmospheric Photodissociation Rates," Journal of Geophysical Research, Vol. 81, 1976, pp. 1125-1132.

Luther, Frederick M. and Donald J. Wuebbles, "What Is the Importance of Multiple Scattering in Calculations of Photodissociation Rates?" invited paper presented at the Middle Atmosphere Program Planning Conference, Urbana, IL, June 21-24, 1976, LLNL Report No. UASG 76-16.

Potter, Gerald L., Michael C. MacCracken, Hugh W. Ellsaesser, and Frederick M. Luther, "Possible Climatic Impact of Tropical Deforestation," Nature, Vol. 258, No. 5537, December 25, 1975, pp. 697-698.

Potter, Gerald L., and Hugh W. Ellsaesser, "Climate Consequences of the Removal of the Tropical Rain Forest," presented at American Geophysical Union Fall Meeting, San Francisco, CA, 8-12 December 1975, LLNL Report No. UCRL-77286 (Abstract).

U.S. DEPARTMENT OF ENERGY,
LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

FAA Interagency Agreement No.: DOT-FATQWAI-653 between Department of Transportation, Federal Aviation Administration and U.S. Department of Energy

July 1976 to September 1978

Principal Investigator: Fred Luther

Title:

Purpose: To continue model refinement started under DOT-TSC-(RA)-76-1 with improved tropospheric chemical cycles. Also, to process ozone data obtained from the USAF Block 5-D satellite and perform global data analysis.

Publications:

Ackerman, M., D. Frimont, C. Muller, and D. J. Wuebbles, "Stratospheric Methane Measurements and Predictions," Pageoph, Vol. 117, 1978, pp. 367-380.

Burt, James E., and Luther, Frederick M., "Effect of Receiver Orientation on Erythema Dose," Photochemistry and Photobiology, Vol. 29, 1979, pp. 85-91, LLNL Report No. UCRL-80334 (Review and Preprint).

Chang, Julius S., "An Assessment of the Diagnostic Capabilities of Stratospheric Models," presented at the WMO Symposium on the Geophysical Aspects and Consequences of Changes in the Composition of the Stratosphere, Toronto, June 26-30, 1978.

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____. "Tropospheric Modeling," presented at the Gordon Conference on Environmental Sciences: Air, New Hampton, VA, August 15-19, 1977.

Chang, Julius S. and William H. Duewer, "Modeling Chemical Processes in the Stratosphere," Annual Review of Physical Chemistry, Vol. 30, 1979, pp. 443-469.

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U.S. DEPARTMENT OF ENERGY,
LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

FAA Interagency Agreement No. DOT-FATQWAI-653 (cont)

Publications: (cont)

Chang, Julius S., William H. Duewer, and Donald J. Wuebbles, "The Atmospheric Nuclear Tests of the 50's and 60's: A Significant Test of Ozone Depletion Theories," Journal of Geophysical Research, Vol. 84, 1979, pp. 1755-1765, LLNL Report No. UCRL-80246 (preprint and review).

Chang, Julius S., and Joyce E. Penner, "Analysis of Global Budgets of Halocarbons," Atmospheric Environment, Vol. 12, 1978, pp. 1867-1873, LLNL Report No. UCRL-79318 (Abstract).

Chang, Julius S., and Donald J. Wuebbles, "Fully Diurnal Averaged Model of the Stratosphere," presented at IAGA/IAMAP Joint Assembly, Seattle, WA, August 22-September 3, 1977, LLNL Report No. UCRL-79317 (Abstract).

____. "A Theoretical Model of Global Tropospheric OH Distribution," Proceedings of the Joint AGU/AMS Symposium on the Non-Urban Tropospheric Composition, Hollywood, FL, November 10-12, 1976, LLNL Report No. UCRL-78392 (preprint).

Duewer, William H., "Evaluation of the Sums and Densities of Vibrational Energy Levels for Coupled Anharmonic Oscillator Models of Small Molecules and Some Implications for RRKM Calculations," presented at the 173rd National Meeting of the American Chemical Society, New Orleans, LA, 20-25 March 1977, LLNL Report No. UCRL-7895 (Abstract).

Duewer, William H., and John J. Walton, "Potential Effects of Commercial Aviation on Region-Wide Air Quality in San Francisco Bay Area," Proceedings of Air Quality and Aviation: An International Conference, October 16-18, 1978, Reston, VA, November 1978, FAA-EE-78-26, pp. 88-102.

Duewer, William H., Donald J. Wuebbles, and Julius S. Chang, "The Effects of a Massive Pulse Injection of NO_x into the Stratosphere," presented at the WMO Symposium on Geophysical Aspects and Consequences of Changes in the Composition of the Stratosphere, Toronto, Canada, June 26-30, 1978, LLNL Report No. UCRL-80379 (Preprint, April 1978).

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Duewer, William H., Donald J. Wuebbles, Hugh W. Ellsaesser, and Julius S. Chang, "Authors' Reply to Comment by Johnston and Nelson," Journal of Geophysical Research, Vol. 82, 1977, pp. 2599-2605.

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U.S. DEPARTMENT OF ENERGY,
LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

FAA Interagency Agreement No. DOT-FATQWAI-653 (cont)

Publications: (cont)

Ellis, James S., and Thomas H. Vonder Haar, "The Earth's Radiation Budget Sensitivity to Cloud Amount as Determined from Satellite Measurements," presented at the IAGA/IAMAP Joint Assembly, Seattle, WA, August 22-September 3, 1977, LLNL Report No. UCRL-77917 (Preprint).

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U.S. DEPARTMENT OF ENERGY,
LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

FAA Interagency Agreement No. DOT-FATQWAI-653 (cont)

Publications: (cont)

Lovill, James E., Thomas J. Sullivan, Joseph B. Knox, and John A. Korver, "Satellite Ozone Analysis Center (SOAC)," UCRL-78092, presented at Joint Symposium on Atmospheric Ozone, August 9-17, 1976, Dresden, Germany.

Lovill, James E., Thomas J. Sullivan, Roger L. Weichel, J.G. Huebel, John A. Korver, James S. Ellis, P.P. Weidhass, and F.A. Phelps, Preliminary Global Total Ozone Results as Inferred from Measurements of a New Satellite Cross-Track Scanning, Multifilter Radiometer, UASG-78-8, January 1978.

____. Total Ozone Retrieval from Satellite Multichannel Filter Radiometer Measurements, ULCRL-52473, May 28, 1978, LLNL Report No. UCRL-52473.

Luther, Frederick M., Annual Report of the Lawrence Livermore Laboratory to the FAA on the High Altitude Pollution Program - 1978, FAA-EE-79-04, UCRL-50042-78, September 1978.

____. Annual Report of Lawrence Livermore Laboratory to the High Altitude Pollution Program - 1977, FAA-EE-78-09, UCRL-50042-77, May 1978.

____. LLNL First Annual Report to HAPP-1976, FAA-EQ-77-6, June 1976.

____. "Effect of Multiple Scattering on Ozone Reduction by NO_x and CFM's," UCRL-79297 (Abstract); also, presented at the IAGA/IAMAP Joint Assembly, Seattle, WA, August 22-September 3, 1977.

____. "Effects of Stratospheric Perturbations on the Solar Radiation Budget," WMO Symposium on the Geophysical Aspects and Consequences of Changes in the Composition of the Stratosphere, Toronto, Canada, June 26-30, 1978, WMO-No. 511, LLNL Report No. UCRL-80429 (preprint).

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Luther, Frederick M. and William H. Duewer, "Effect of Changes in Stratospheric Water Vapor Abundance on Predicted Ozone Reductions," presented at the IAGA/IAMAP Joint Assembly, Seattle, WA, Aug. 22-Sept. 3, 1977, LLNL Report No. UCRL-79296.

FAA Interagency Agreement No. DOT-FATQWAI-653 (cont)

Publications: (cont)

____. "Effect of Changes in Stratospheric Water Vapor on Ozone Reduction Estimates," Journal of Geophysical Research, Vol. 83, 1978, pp. 2395-2402, LLNL Report No. UCRL-79660 (preprint and review).

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Luther, Frederick M., Donald J. Wuebbles, William H. Duewer, and Julius S.Chang, "Effect of Multiple Scattering on Species Concentrations and Model Sensitivity," Journal of Geophysical Research, Vol. 83, 1978, pp. 3563-3570, LLNL Report No. UCRL-79946 (preprint and review).

Penner, Joyce E., and Julius S. Chang, "Possible Variations in Atmospheric Ozone Related to the Eleven Year Solar Cycle," Geophysical Research Letters, Vol. 5, No. 10, October 1978, pp. 817-820, also presented at WMO Symposium on the Geophysical Aspects and Consequences of Changes in the Composition of the Stratosphere, Toronto, Canada, 26-30 June 1978.

Wuebbles, Donald J., "Alternate Fluorocarbons: Tropospheric Lifetimes and Potential Effects on Stratospheric Ozone," presented at IAGA/IAMAP Joint Assembly, Seattle, WA, August 22-September 3, 1977, LLNL Report No. UCRL-79303 (Abstract).

____. A Reexamination of Potential Space Shuttle Effects on the Stratosphere, LLNL Report No. UCID-17689, 1977.

____. "A Theoretical Study of Solar Eclipse Effects on the Stratosphere," presented at the AMS Meeting on Meteorology of the Upper Atmosphere, Boston, MA, October 24-27, 1978, LLNL Report No. UCRL-80963.

Wuebbles, Donald J., and Julius S. Chang, "A Theoretical Study of Eclipse Effects on the Stratosphere," Geophysical Research Letters, Vol. 6, 1979, pp. 179-182.

Wuebbles, Donald J., Julius S. Chang, and William H. Duewer, "Effects of the SST in a Chlorinated Atmosphere," LLNL Report No. UCRL-78803 (Abstract), presented at 173rd National Meeting of the American Chemical Society, New Orleans, LA, 20-25 March 1977.

Wuebbles, Donald J., Julius S. Chang, and Frederick M. Luther, "The Diurnal Model of Chlorine Chemistry in the Stratosphere," LLNL Report No. UCRL-78454 (Abstract), presented at International Conference on the Stratosphere and Related Problems, Logan, UT, 15-17 September 1976.

Wuebbles, Donald J., and Frederick M. Luther, "Preliminary Study of Solar Power Satellites Program Potential Effect on Stratospheric Chemistry," LLNL Report No. UASG 78-41, 1978.

U.S. DEPARTMENT OF ENERGY,
LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

FAA Interagency Agreement No.: DOT-FA79WAI-034 between Department of Transportation, Federal Aviation Administration and U.S. Department of Energy

April 1979

Principal Investigator: Fred Luther

Purpose: To develop and maintain a state-of-the-art capability presently existing at LLNL to numerically model all atmospheric phenomena relevant to HAPP requirements. Also, to receive and reduce ozone data sensed by the USAF Block 5-D satellite.

Publications:

Chang, Julius S., "Some Fundamental Concepts and Problems in Stratospheric Modeling," presented at NATO Advanced Study Institute on Atmospheric Ozone, Aldeia das Acoteias, Albufeira, Algarve, Portugal, October 1-13, 1979.

____. "Stratospheric Chemistry: Theory and Models," The Institute of Atmospheric Physics, Chinese Academy of Science, Beijing, People's Republic of China, April-May 1980. A series of six lectures.

Chang, Julius S., and Donald J. Wuebbles, "One-Dimensional Coupled Transport and Chemical Kinetics Models of the Stratosphere," in <u>Proceedings of the NATO Advanced Study Institute on Atmospheric Ozone: Its Variation and Human Influences</u>, Aldeia das Acoteias, Algrave, Portugal, October 1-13, 1979, FAA-EE-80-20, pp. 749-761, May 1980, LLNL Report No. UCRL-83790.

Duewer, William H., "Recombination-Dissociation Theory for NO_2 and NO CP," appeared as a comment in <u>Journal of Physical Chemistry</u>, Vol. 83, No. 18, 1979.

____. "Tropospheric Methane: Response to Stratospheric Ozone Trends," presented at the International Meeting of the Union of Geodesy and Geophysics, Canberra, Australia, December 2-15, 1979, LLNL Report No. UCRL-82968, 1979.

Duewer, W.H., and Donald J. Wuebbles, "Effects of Speculative Reaction and Mechanisms on Predicted Ozone Perturbations," presented at 14th Informal Conference on Photochemistry, Newport Beach, CA, March 30-April 3, 1980, LLNL Report No. UCRL-82950.

Ehhalt, D.H., J.S. Chang, and D.M. Butler, "The Probability Distribution of Ozone Changes Predicted from Anthropogenic Activities," <u>Journal of Geophysical Research</u>, Vol. 84, 1979, pp. 7889-7894.

U.S. DEPARTMENT OF ENERGY,
LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

FAA Interagency Agreement No.: DOT-FA79WAI-034 (cont)

Publications: (cont)

Ellsaesser, Hugh, W., "Man's Effect on Stratospheric Ozone," invited paper, Biogeochemistry of Ancient and Modern Environments, Proceedings of 4th International Symposium on Environmental Biogeochemistry (ISEB), Canberra, Australia, Aug. 26-Sept. 4, 1979, Australian Academy of Sciences, Canberra, Australia, 1980, pp 383-393, LLNL Report No. UCRL-82556.

____. "UV-B Radiation Reaching the Ground Computed as a Function of Total Ozone, Solar Zenith Angle and Surface Pressure," presented at the NATO Advanced Research Institute on the Effects of Solar Ultraviolet Radiation on Marine Ecosystems, Copenhagen, Denmark, July 28-31, 1980, LLNL Report No. UCRL-84528.

____. "Should We Trust Models or Observations?" invited paper presented in session on "The SST Controversy: Ten Years Later," at Annual Meeting of AAAS, Toronto, Canada, January 3-18, 1981.

____. Sources and Sinks of Stratospheric Water Vapor," Proceedings of the NATO Advanced Study Institute on Atmospheric Ozone: Its Variation and Human Influences, Aldeia das Acoteias, Algarve, Portugal, October 1-13, 1979, FAA-EE-80-20, May 1980, pp 283-300, LLNL Report No. UCRL-83611.

Ellsaesser, Hugh W., John E. Harries, Dieter Kley, and Rudolf Penndorf, "Stratospheric H_2O," Planetary and Space Science, Vol. 28, 1980, pp. 827-845, LLNL Report Nos. UCRL-82512 and 82542.

Lovill, James E., J.S. Ellis, and P.P. Weidhaas, "The Global Observation of Atmospheric Ozone by Satellite," presented at WMO Technical Conference on Regional and Global Observation of Atmospheric Pollution Relative to Climate, University of Colorado, Boulder, CO, August 20-24, 1979, LLNL Report No. UCRL-82028.

Luther, Frederick M., Annual Report of the Lawrence Livermore Laboratory to the FAA on the High Altitude Pollution Program - 1979, FAA-EE-80-39, LLLNL Report No. UCRL-50042-79, September 1979.

____. Annual Report of Lawrence Livermore National Laboratory to the FAA on the High Altitude Pollution Program - 1980, LLL Report No. UCRL-50042-80, December 1980.

____. "Ozone Depletion Models," presented at the NATO Advanced Research Institute on the Effects of Solar Ultraviolet Radiation on Marine Ecosystems, Copenhagen, Denmark, July 28-31, 1980, LLNL Report No. UCRL-84529.

____. "Photochemical Modeling: A Numerically Fast Scheme for Treating Multiple Scattering," Volume of Extended Abstracts, International Radiation Symposium, Fort Collins, CO, August 11-16, 1980, LLNL Report No. UCRL-83031 (Extended Abstract).

U.S. DEPARTMENT OF ENERGY,
LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

FAA Interagency Agreement No.: DOT-FA79WAI-034 (cont)

Publications: (cont)

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Luther, Frederick M., Julius S. Chang, William H. Duewer, Joyce E. Penner, R.L. Tarp, and Donald J. Wuebbles, Potential Environmental Effects of Aircraft Emissions, FAA-EE-79-23, October 1979, LLNL Report No. UCRL-52861.

Luther, Frederick M., J.S. Ellis, J.E. Lovill, T.J. Sullivan, and R.L. Weichel, "Global Distribution of Total Ozone During January and February 1979 as Determined from DMSP Multichannel Filter Radiometer Measurements," Proceedings of the Quadrennial Ozone Symposium, Boulder, CO, August 4-9, 1980, LLNL Report No. UCRL-84070.

Luther, Frederick M., and R.L. Weichel, "Determination of Total Ozone From DMSP Multichannel Filter Radiometer Measurements," in Proceedings of the Quadrennial Ozone Symposium, Boulder, Colorado, August 4-9, 1980, LLNL Report No. UCRL-84069.

Penner, Joyce E., "Effect of Increased CO_2 on Stratospheric Ozone," presented at AGU Fall Meeting, San Francisco, CA, December 1980.

___. "Increases in CO_2 and Cholorofluoromethanes: Coupled Effects on Stratospheric Ozone," presented at Quadrennial International Ozone Symposium, Boulder, Co, August 4-9, 1980, LLNL Report No. UCRL-84058, 1980.

Penner, Joyce E., and Julius S. Chang, "The Relation Between Atmospheric Trace Species Variability and Solar UV Variability," submitted to Journal of Geophysical Research, 1979, LLNL Report No. UCRL-83029 (Review 1).

Penner, Joyce E., L.P. Golen, and R.W. Mensing, " A Time Series Analysis of Umkehr Data From Arosa," submitted to Journal of Atmospheric Sciences, 1981, LLNL Report No. UCRL-85420.

Penner, Joyce E., and Frederick M. Luther, "Effects of Temperature Feedback and Hydrostatic Adjustment in a Stratospheric Model," accepted for publication in Journal of Atmospheric Sciences, LLNL Report No. UCRL-83250, also presented in Brussels and Julich, October 1979, and at AGU Meeting in San Francisco, December 1979.

Rasmussen, R.A., M.A.K. Khalil, and J.S. Chang, " Atmospheric Trace Gases Over China," October 1930 (preprint).

Wine, P.H., A.R. Ravishankara, N.M. Kreutter, R.C. Shah, J.M. Nicovich, R.L. Thomson and D.J. Wuebbles, "Rate of Reaction of OH with HNO_3," Journal of Geophysical Research, Vol. 86, pg.1105, February 1981.

U.S. DEPARTMENT OF ENERGY,
LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

FAA Interagency Agreement No.: DOT-FA79WAI-034 (cont)

Publications: (cont)

Wuebbles, Donald J., "A Comparison Study Between 1-D Models," LLNL Report No. UASG 80-21, 1980.

____. "Impact of New OH + HNO_3 Rate Measurement on Models of Atmospheric Chemistry," LLNL Report No. UCID-18727, 1980.

____. "A Summary of Current Two-Dimensional Transport-Kinetics Models," LLNL Report No. USAG 80-25, 1980.

____. "The Treatment of Dynamical Processes in Two-Dimensional Models of the Troposphere and Stratosphere," LLNL Report No. UCID-18771, 1980.

Wuebbles, Donald J., and Julius S. Chang, "A Study of the Effectivenss of the CℓX Catalytic Ozone Loss Mechanisms," in Proceedings of the Quadrennial International Ozone Symposium, Boulder, CO, Aug. 4-9, 1980, LLNL Report No. UCRL-84071.

Wuebbles, Donald J., and W.H. Duewer, "Effect of Recent Kinetics Measurements on Our Understanding of Chemical Processes in the Troposphere and Stratosphere," presented at 14th Informal Conference on Photochemistry, Newport Beach, CA, March 30-April 3, 1980, LLNL Report No. UCRL-83960.

Wuebbles, Donald J., and Frederick M. Luther, "Sensitivity of Quantum Yield for O (^{1}D) Production from Ozone Photolysis," LLNL Report No. UCID-18734, 1980.

Wuebbles, D.J., and R.L. Tarp, "Potential Changes to Stratospheric Ozone from Possible Chlorofluorocarbon Production Scenarios," LLNL Report No. UCID-18583, 1980 (sponsored by EPA).

U.S. DEPARTMENT OF ENERGY, LOS ALAMOS SCIENTIFIC LABORATORY (LASL)

FAA Interagency Agreement No.:	DOT-FA78WAI-860, between U.S. Department of Energy and U.S. Department of Transportation, Federal Aviation Administration
	March 1978 to December 1980
Principal Investigator:	Malcolm Fowler
Title:	Investigation of Global Transport Experiment
Purpose:	To investigate the possibility of performing an experiment to obtain the global three-dimensional transport parameters which are necessary to the improvement of the numerical models of the atmosphere used in assessing the long-term ozone distribution effects of aircraft.

Publications:

Fowler, Malcolm and Paul Guthals, "Feasibility Study-Experiment to Obtain Global Atmospheric Data for Three-Dimensional Transport Model Improvement," Final Report, (Draft) submitted January 1980.

U.S. DEPARTMENT OF ENERGY, LOS ALAMOS SCIENTIFIC LABORATORY (LASL)

FAA Interagency Agreement No.: DOT-FA76WAI-628 between Department of Transportation, Federal Aviation Administration and U.S. Department of Energy

April 1976 to July 1977

Principal Investigator: P. Guthals

Title: Processing, Reduction, and Data Analysis of April and May 1975 CIAP/Airstream Data

Purpose: To perform data processing of the CIAP/Airstream and deliver to scientist in charge (Dr. Murcray of the University of Denver) to determine the HNO_3 column density and to compare the results with earlier measurements.

Publications:

Murcray, David G., Variation of HNO_3 Total Column Density with Latitude, Final Report, July 8, 1977.

UNIVERSITY OF CALIFORNIA, IRVINE

FAA Contract No.:	DOT-FA78WA-4248	September 1978 to April 1980
Principal Investigator:	Mario J. Molina	
Title:	Measurement of the Photolytic Parameters for Pernitric Acid	
Purpose:	To determine the cross section in the UV and IR for HO_2NO_2 and to deduce quantum yields for its photolytic decomposition.	

Publications:

Molina, Luisa T., and Mario J. Molina, "Ultraviolet Absorption Cross Sections of HO_2NO_2 Vapor", Journal of Photochemistry, Vol. 15, No. 2, April 1980, pp. 97-108; also published as FAA Report No. FAA-EE-80-07.

UNIVERSITY OF CALIFORNIA, IRVINE

FAA Contract No.:	DTFA01-80-C-10084 July 1980 to July 1982
Principal Investigator:	Mario J. Molina
Title:	Measurement of Hydroxyl Radicals Reaction with Hydrogen Peroxide
Purpose:	To measure the absolute rate of the gas phase reaction of hydroxyl radicals (OH) with hydrogen peroxide (H_2O_2)

Publications:

Lamb, John J., Luisa T. Molina, Craig A. Smith, and Mario J. Molina, "Rate Constant for the OH + $H_2O_2 \rightarrow HO_2 + H_2O$ Reaction," Journal of Physical Chemistry, 87, pp. 4467-4470, 1983.

Molina, Mario, J., Luisa T. Molina, Craig A. Smith, and John J. Lamb, Rate Constant of the OH + $H_2O_2 \rightarrow HO_2 + H_2O$ Reaction, Final Report July 1982, FAA-EE-82-17.

UNIVERSITY OF CALIFORNIA, IRVINE

FAA Contract No.:	DOT-FA79WA-4269	November 1978 to April 1979
Principal Investigator:	F. Sherwood Rowland	
Title:	State-of-the-Art Assessment of Atmospheric Chemistry - A Workshop	
Purpose:	To perform a study of the state-of-the-art of the impact of all aspects of aviation on air quality by considering data and other input from all appropriate segments of government, scientific and technical community, aviation-related industries and other interested parties.	

Publications:

Rowland, F. Sherwood, State-of-the-Art Assessment of Atmospheric Chemistry - A Workshop, Final Report, FAA-EE-79-21, November 1979.

UNIVERSITY OF CALIFORNIA, IRVINE

FAA Contract No.: DTFA01-80-C-10066 May 1980 to April 1982

Principal Investigator: F. Sherwood Rowland

Title: State-of-the-Art Assessment (II) of Atmospheric Chemistry

Purpose: To conduct and critique a workshop study of the state-of-the-art of current concepts in atmospheric chemistry.

Publications:

Rowland, F. S., "State-Of-The-Art Assessment (II) of Atmospheric Chemistry a Workshop," Final Report April 1982, FAA-EE-82-12.

UNIVERSITY OF CAMBRIDGE

FAA Contract No.: DOT-FA77WA-4054 September 1977 to June 1982

Principal Investigator: Brian A. Thrush

Title: Measurement of Perhydroxyl Reaction Rates

Purpose: To measure the absolute rate and temperature dependence of the reactions of HO_2, with HO_2, OH, SO_2, Cl, NO, O_3, Br, and H

Publications:

Burrows, John P., D.I. Cliff, G.W. Harris, Brian A. Thrush, and J.P.T. Wilkinson, Laboratory Studies of the Reactions of Hydroperoxy Radicals (HO_2) Having Stratospheric Importance, presented at the WMO Symposium on the Geophysical Aspects and Consequences of Changes in the Composition of the Stratosphere, Toronto, Canada, June 26-30, 1978.

____. "Atmospheric Reactions of the HO_2 Radical Studied by Laser Magnetic Resonance Spectroscopy," Proceedings of the Royal Society of London, Vol. A 368, pp. 463-481, 1979.

Burrows, John P., D.I. Cliff, P.B. Davies, G.W. Harris, B.A. Thrush and, J.P.T. Wilkinson, "Pressure Broadening of the Lowest Rotational Transition of OH Studied by Laser Magnetic Resonance," Chem. Phys. Letters, 65, pg. 197, 1979.

Buchanan, J.W., B.A. Thrush, and G.S. Tyndall, "The Absolute Intensity of the ν_3 Band of HO_2," Chem. Phys. Letters, 103, pg. 167, 1983.

Thrush, B.A., "Laser Magnetic Resonance Spectroscopy of Free Radicals and its Application to Atmospheric Chemistry," European Spectroscopy News 20, pg. 15, 1978.

____. "Laboratory Kinetic Studies in Relation to Atmospheric Chemistry," Ber. Bunsengesell. Phys. Chem., 82, pg. 1159, 1978.

____. "Aspects of the Chemistry of Ozone Depletion," Phil. Trans. Roy. Soc., A290. 505. 1979.

____. "The Chemistry of the Stratosphere," Philosophical Transactions of the Royal Society of London, Vol. A 296, pp. 149-160, 1980.

____. "Laboratory Studies of the Chemistry of the Stratosphere," Michael Polanyi Lecture of Chemical Society presented at the 5th International Symposium on Gas Kinetics, Southampton, England, July 14-17, 1980.

____. "Laser Magnetic Resonance Spectroscopy and its Application to Atmospheric Chemistry," Accounts of Chemical Research, Vol. 14, pg. 116, 1981.

Thrush, B.A., and G.S. Tyndall, "Reactions of HO_2 Studied by Flash Photolysis with Diode Laser Spectroscopy," J.C.S. Faraday II, Vol. 78, pg. 1469, 1982.

UNIVERSITY OF CAMBRIDGE

FAA Contract No.: DOT-FA77WA-4054 (cont)

Publications: (cont)

____. "The Rate of Reaction Between HO_2 Radicals at Low Pressures," Chem. Phys. Letters, Vol. 92, pg. 232, 1982.

Thrush, B.A., and J.P.T. Wilkinson, "Pressure Dependency of the Rate of Reaction Between HO_2 Radicals," Chem. Phy. Letters, Vol. 66, pg. 441, 1979.

____. "The Rate of Reaction of HO_2 Radicals with HO and with NO," Chem. Phys. Letters, Vol. 81, pg. 1, 1981.

____. "The Rate of Reaction Between H and HO_2," Chem. Phys. Letters, Vol. 84 pg. 17, 1981.

UNIVERSITY OF DENVER

FAA Contract No.: DOT-FA77WA-3949 February 1977 to August 1978

Principal Investigator: David G. Murcray

Title: *Data Interpretation of Measurements of Trace Gases*

Purpose: To determine the error in deducing NO and NO_2 *altitude profiles from infrared solar spectra obtained* at high altitudes during sunrise and sunset.

Publications:

Goldman, Aaron, and R.S. Saunders, "Analysis of Atmospheric Infrared Spectra for Altitude Distribution of Atmospheric Trace Constituents. I: Method of Analysis," Journal of Quantitative Spectroscopy and Radiative Transfer, Vol. 21, 1979.

Murcray, David G., Aaron Goldman, G.R. Cook, D.K. Rolens, and Lawrence R. Megill, On the Interpretation of Infrared Solar Spectra for Altitude Distribution of Atmospheric Trace Constituents, FAA-EE-78-30, August 1978.

Murcray, David G., J.M. Williams, David B. Barker, Aaron Goldman, C.M. Bradford, and G. R. Cook, "Measurements of Constituents of Interest in the Photochemistry of the Ozone Layer Using Infrared Techniques," presented at WMO Symposium on the Geophysical Aspects and Consequences of Changes in the Composition of the Stratosphere, Toronto, Canada, June 26-30, 1978.

UNIVERSITY OF DENVER

FAA Contract No.: DTFA01-80-C-10039 March 1980 to April 1982

Principal Investigator: David G. Murcray

Title: Analysis of infrared data and performance of a dedicated balloon flight to detect N_2O_5.

Purpose: To analyze the flight data previously obtained by the Bomen interferometer system to obtain ozone line parameters which are not available from laboratory spectra.

The contractor shall analyze the flight data obtained in past Government sponsored University of Denver balloon flights by the atmospheric emission spectrometer system for information on trace atmospheric constituents and shall report on at least three water vapor altitude profiles obtained from these data. The contractor shall perform a dedicated balloon flight using an atmospheric emission spectrometer to detect the presence of N_2O_5 in the stratosphere.

Publications:

Barbe, A., C. Secroun and P. Jouve, Laboratoire de Physique Moleculaire, Equipe de Recherche Associee au CNRS, Faculte des Sciences, Reims 51062, France and A. Goldman and D.G. Murcray University of Denver, Denver Co., "High-Resolution Infrared Atmospheric Spectra of Ozone in the 10-um Region: Analysis of (²1 + ²2) - ²2 Band," <u>Journal of Molecular Spectroscopy</u> 86, pp. 286-297, 1981.

Gillis, J.R., A. Goldman, W.J. Williams, and D.G. Murcray, "Stratospheric Ozone Profiles from High Resolution UV Spectra Obtained With A Balloon-borne Spectrometer," <u>Applied Optics,</u> Vol. 21, No. 3 pg. 413, February 1, 1982.

Goldman, A., and D.G. Murcray, "Recent Results in the Analysis of High-Resolution Infrared Atmospheric Transmission Spectra," <u>SPIE</u> Vol. 277, Atmospheric Transmission, 1981.

Goldman, A., and J.R. Gillis, and D.G. Murcray, University of Denver, and A. Barbe, C. Secroun, Laboratoire de Physique Moleculaire, Equipe de Recherche Associee au CNRS Faculte des Sciences, Reims 51062, France, "Analysis of the γ2 and 2γ 2-γ2. Ozone Bands from High-Resolution Infrared Atmospheric Spectra," <u>Journal of Molecular Spectroscopy</u> 96, pp. 279-287, 1982.

UNIVERSITY OF DENVER

FAA Contract No.: DTFA01-80-C-10039 (cont.)

Publications: (cont)

Goldman, A., D. G. Murcray, F. J. Murcray, F. H. Murcray and W. J. Williams, University of Denver, and M. T. Coffey, W. G. Mankin, National Center for Atmospheric Research (NCAR), "AIAA 82-0008 Recent Spectroscopic Measurements of NO_x in the Lower Stratosphere," AIAA 20th Aerospace Sciences Meeting January 11-14, 1982, Orlando, Florida.

Goldman, A., D. G. Murcray, and F. J. Murcray, University of Denver, and E. Niple, Perkin-Elmer Corporation, Danbury, Connecticut, "High Resolution IR Balloon-Borne Solar Spectra and Laboratory Spectra in the HNO_3 1720-cm $^{-1}$ region: an analysis," 15 November 1980, Vol. 19, No. 22 Applied Optics.

Murcray, David, G., "Stratospheric Emission and Absorption Data: Measurement and Analysis," Final Report April 1982.

UNIVERSITY OF WYOMING

FAA Contract No.: DOT-FA76WA-3782 July 1977 to July 1981

Principal Investigator: David J. Hofmann

Title: Cooperative Stratospheric Aerosol Research Program

Purpose: To perform a joint aerosol measurement program with the University of Leningrad consisting of simultaneous measurements by both groups in the U.S. and the U.S.S.R. In addition, prepare a joint report and provide supporting measurement to NASA's NIMBUS 7 satellite.

Publications:

Hofmann, David J., and James M. Rosen, "Balloon Observations of a Particle Layer Injected by a Stratospheric Aircraft at 23 km," Geophysical Research Letters, Vol. 5, No. 6, June 1978, pp. 511-14.

Hofmann, David J., James M. Rosen, K. Ya. Kondratyev, V. Ivanov, A. Laktionov, and L. Ivlev, "Comparison of Results Obtained During the U.S.S.R.- U.S.A. Cooperative Aerosol Measurement Program in Laramie," WMO Bulletin, Vol. 27, 1978, p. 186.

Rosen, James M., and David J. Hofmann, University of Wyoming/Leningrad State University Cooperative Stratospheric Aerosol Research Program, FAA-AEQ-78-22, July 1978.

Rosen, James M., N.J. Kjomi, and David J. Hofmann, "Cooperative Research Between the U.S.A. and the U.S.S.R," WMO Bulletin, Vol. 25, 1976, p. 236.

______. "Cooperative U.S.-U.S.S.R. Balloon Flights," Bulletin of the American Meteorological Society, Vol. 57, 1976, p. 225.

YORK UNIVERSITY

FAA Contract No.: DOT-TSC-1203 June 1976 to December 1978

Principal Investigator: Harold I. Schiff

Title: Laboratory Study of Chemical Reactions

Purpose: To determine the reaction rates and products of $O(^1D) + N_2O$ and of $O(^3P) + N_2O_5$.

Publications:

Schiff, Harold I., Measurement of the Branching Ratios for the Reaction of $O(^1D_2)$ with N_2, Final Report, May 1978.

YORK UNIVERSITY

FAA Contract No.: DOT-FA77WA-3931 January 1977 to November 1979

Principal Investigator: Harold I. Schiff

Title: In Situ Measurements of NO, NO_2 and N_2O_5 in the Stratosphere from Balloons

Purpose: To perform four balloon flights to make simultaneous NO, NO_2 and if obtainable N_2O_5 measurements throughout the course of a day. Also, to investigate laser diode technology for measurement of NO and NO_2 to better than 100 pptv.

Publications:

Roy, Colin R., Ian E. Galbally, and Brian A. Ridley, "Measurements of Nitric Oxide in the Stratosphere of the Southern Hemisphere," Quarterly Journal of the Royal Meteorological Society, Vol. 106, No. 450, October 1980.

XONICS, INC.

FAA Contract No.:	DOT-FA78WA-4262	September 1978 to February 1980
Principal Investigator:	Robert A. Young	
Title:	*Measurement of the Rate of OH + ClO*	
Purpose:	To determine the rate of reaction of OH with ClO as a function of temperature and pressure.	

Publications:

Young, Robert A., Laboratory Measurements of the Reaction Rate of Hydroxyl Radicals (OH) with Chlorine Monoxide (ClO), Final Report, FAA-EE-80-18, June 1980.

APPENDIX C

HIGH ALTITUDE POLLUTION PROGRAM

SCIENTIFIC ADVISORY COMMITTEE

HIGH ALTITUDE POLLUTION PROGRAM

SCIENTIFIC ADVISORY COMMITTEE

Dr. F. Sherwood Rowland, Chairman
University of California
Department of Chemistry
Irvine, California 92717

Dr. Marcel E. H. Ackerman
Institut d'Aeronomie Spatiale
de Belgique
3 Avenue Circulaire
B-1180 Brussels
Belgium

Dr. Rumen D. Bojkov
Chief, Atmospheric Sciences Division
World Meteorological Organization
Case Postale No. 5
CH-1211 Geneva 20
Switzerland

Dr. Julius S. Chang
National Center for Atmospheric Research
P.O. Box 3000
Boulder, Colorado 80307

Dr. Ralph J. Cicerone
National Center for Atmospheric Research
P.O. Box 3000
Boulder, Colorado 80307

Prof. Dr. Paul Crutzen
Max-Planck-Institut fur Chemie
Air Chemistry Department
Postfach 3060
Saarstra 23
D-6500 Mainz, West Germany

Dr. Edwin F. Danielsen
National Aeronautics and Space
Administration
Ames Research Center
Code: 245-5
Moffett Field, California 94035

Prof. Dr. Dieter H. Ehhalt
Institut fur Chemie
3 Atmospaerische Chemie Der
Kernforschung Sanlage
Julich GMBH Postfach 1913
D-5170 Julich, West Germany

Dr. Harold S. Johnston
University of California
Department of Chemistry
Berkeley, California 94720

Mr. George Kittredge
U.S. Environmental Protection Agency
Code: AW-455
401 M Street, S.W.
Washington, D.C. 20460

Dr. J. E. Lovelock
Coombe Mill
St. Giles-on-the-Heath
Launceston, Cornwall
England

Dr. Jerry D. Mahlman
National Oceanic and Atmospheric
Administration
Princeton University
P.O. Box 308
Princeton, New Jersey 08540

Dr. Robert J. Murgatroyd
6 Ashley Road
Farnborough
Hampshire GU 14 7HA
England

Dr. Randall E. Murphy
Optical Physics, OPR, Stop-30
Air Force Geophysics Laboratory
Hanscom Air Force Base
Bedford, Massachusetts 01731

Dr. Robert C. Oliver
Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, Virginia 22311

Dr. A. B. Pittock
C.S.I.R.O.
Division of Atmospheric Physics
P.O. Box 77
Mordialloc, Victoria 3195
Australia

Dr. James N. Pitts, Jr.
Statewide Air Pollution Research
Center
University of California
Riverside, California 92521

Dr. George D. Robinson
Center for the Environment and Man
275 Windsor Street
Hartford, Connecticut 06120

Mr. Robert W. Rummel
Robert W. Rummel Associates, Inc.
908 W. Power Road #1189
Mesa, Arizona 85206

Dr. Harold I. Schiff
York University
Department of Chemistry
4700 Keele Street
Downsview, Ontario
Canada M3J IP3

Dr. Arthur L. Schmeltekopf
National Oceanic and Atmospheric
Administration
Environmental Research Laboratory
Code: 448
Boulder, Colorado 80303

Dr. Shelby G. Tilford
National Aeronautics and Space
Administration
Code: EE
600 Independence Avenue, S.W.
Washington, D.C. 20546

Dr. Adelin Villevieille
Director E.E.R.M.
73-77 Rue de Sevres
92106 Boulogne - Billancourt Cedex
France

Air Commodore Sir Frank Whittle
10327 Wilde Lake Terrace
Columbia, Maryland 21044

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